Foreword

National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE

NOAA Fisheries Service
Northeast Cooperative Research Partners Program

The National Marine Fisheries Service (NOAA Fisheries Service), Northeast Cooperative Research Partners Program (NCRPP) was initiated in 1999. The goals of this program are to enhance the data upon which fishery management decisions are made as well as to improve communication and collaboration among commercial fishery participants, scientists and fishery managers. NOAA Fisheries Service works in close collaboration with the New England Fishery Management Council's Research Steering Committee to set research priorities to meet management information needs.

Fishery management is, by nature, a multiple year endeavor which requires a time series of fishery dependent and independent information. Additionally, there are needs for immediate short-term biological, oceanographic, social, economic and habitat information to help resolve fishery management issues. Thus, the program established two avenues to pursue cooperative research through longer and short-term projects. First, short-term research projects are funded annually through competitive contracts. Second, three longer-term collaborative research projects were developed. These projects include: 1) a pilot study fleet (fishery dependent data); 2) a pilot industry based survey (fishery independent data); and 3) groundfish tagging (stock structure, movements and mixing, and biological data).

> First, a number of short-term research projects have been developed to work primarily on commercial fishing gear modifications, improve selectivity of catch on directed species, reduce bycatch, and study habitat reactions to mobile and fixed fishing gear.
>
> Second, two cooperative research fleets have been established to collect detailed fishery dependent and independent information from commercial fishing vessels. The original concept, developed by the Canadians, referred to these as "sentinel fleets". In the New England groundfish setting it is more appropriate to consider two industry research fleets. A pilot industry-based survey fleet (fishery independent) and a pilot commercial study fleet (fishery dependent) have been developed.
>
> Additionally, extensive tagging programs are being conducted on a number of groundfish species to collect information on migrations and movements of fish, identify localized or subregional stocks, and collect biological and demographic information on these species.

For further information on the Cooperative Research Partners Programs please contact:

National Marine Fisheries Service (NOAA Fisheries Service)
Northeast Cooperative Research Partners Program

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www.nero.noaa.gov/StateFedOff/coopresearch/

National Oceanic and Atmospheric Administration

SMOOTH BOTTOM NET TRAWL FISHING GEAR EFFECT ON THE SEABED:

U.S. DEPARTMENT OF COMMERCE

INVESTIGATION OF TEMPORAL AND CUMULATIVE EFFECTS

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1.0 INTRODUCTION

To date much of the research on fishing gear-induced habitat impacts focuses on long-term cumulative changes to gravel bottom or rocky substrate communities in areas open to or closed to fishing activity. Because little is known of the historical distribution and density of fishing activity in the open areas, it is difficult to quantify the impact of fishing per unit of effort. In 2000, NOAA/NMFS funded Boat Kathleen A. Mirarchi, Inc. and CR Environmental, Inc.'s proposal to conduct "*Near Term Observations of the Effects of Smooth Bottom Net Trawl Fishing Gear on the Seabed*." Using local fishermen's knowledge, the project team of fishermen and researchers characterized the generally soft substrate sea floor in an area of Essential Fish Habitat at approximately 130 ft of water in a heavily fished area (Mud Hole) and a lightly fished area (Little Tow) off Scituate, MA, in the Massachusetts Bay region of the Gulf of Maine (Figure 1.0-1). The sea floor was surveyed before and after six repetitive passes with smooth bottom net trawl gear (Figure 1.0-2). Parameters examined were the sea floor substrate, water column characteristics, fish and bycatch, the stomach contents of select commercial bottom fish and benthic infaunal and epifaunal communities. Tools successfully used to characterize the sites and elucidate trawling effects included a: side-scan sonar, Hypack navigation software, precision echosounder, remotely operated vehicle (ROV), video sled, benthic dredge; conductivity, depth, oxygen, turbidity sensor (Seabird SeaCat CTD), benthic grab, and net liner during trawling. Similar to other recent studies, the research indicated that the immediate impacts of the net sweep and other ground gear (excluding the heavy doors) on the benthic ecosystem *were not great* (NE Region Essential Fish Habitat Steering Committee, October 2001; Johnson 2002).

For this 2002 study, the experimental design was expanded to explore *temporal* change in the soft bottom habitats at Mud Hole and Little Tow, and the *cumulative impact* of repeated trawling disturbance in this area of Essential Fish Habitat. The established replicate experimental (trawled) corridors (Figures 1.0-3 and 1.0-4) were trawled on average every 1.3 times a week from late July through mid-November 2002 when fixed gear was not in place and the study areas were not closed to groundfishing (i.e. fisheries closures in 2002 were January to April). The replicate experimental (trawled) and reference (non-trawled) corridors were then sampled within each study area (Little Tow and Mud Hole) in July, September and November 2002. All survey gear used in the 2001 study was used in the 2002 study excluding the ROV. A sediment profile imaging camera was added to better document subtle changes in the fabric of the sediment and habitat alteration that could impact larval recruitment and settlement.

1.1 Statutory and Regulatory Basis for Fishing Gear – Essential Fish Habitat Research and Compatibility of this Study with EFH Research Priorities

The 1996 amendments to the Magnuson-Stevens Fishery Conservation and Management Act (M-SFCMA), known as the Sustainable Fisheries Act, obligated the Regional Fishery Management Councils to undertake the following actions:

(1) Identify and characterize the essential fish habitat (EFH) for all species under a Fishery Management Plan FMP);

(2) To the maximum extent practicable, minimize the adverse effects of fishing gear and practices on EFH; and
(3) Identify other actions to encourage the conservation and enhancement of EFH.

For the purposes of these requirements, EFH was defined to include "*those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity*."

Following publication of clarifying guidelines by NMFS the New England Regional Fishery Management Council (NEFMC) began development of a comprehensive EFH amendment to all relevant FMP's. Presently these include Northeast Multispecies (groundfish), Sea Scallops, Sea Herring, Monkfish, and Atlantic Salmon. The intent of the comprehensive or "omnibus" amendment is to identify and characterize EFH for all managed species, to identify both fishing and non-fishing derived threats to those habitats and to identify mechanisms to conserve and enhance those areas.

Recognizing the data to fully support an omnibus habitat amendment were not sufficiently comprehensive or detailed, the NEFMC adopted a progressive approach beginning with broad characterizations and backfilling the nuances and details as information became available. For example, EFH is initially characterized solely by the presence of relevant species. Subsequently, details of population density, reproduction, growth, survival, and production rates are added as information is obtained and compiled.

Similarly, initial characterization of fishing derived impacts was primarily descriptive and limited to identification of the types of fishing gear in use and the geographic range and target species for each.

Recognizing that a scarcity of information could compromise its ability to satisfactorily discharge its multiple responsibilities, the Council began compilation of a research priorities document. In 1999, the U.S. Congress, seeking to facilitate the progress of fisheries research, provide an alternative in response to complaints of NMFS's near monopoly in the field and to provide a revenue source to the ground fishery which had been declared an economic disaster, funded a co-operative research program for New England. The principal centers for disbursement of co-operative research funds were the Northeast Consortium and the Co-operative Research Partners Initiative (CRPI), an office within the NMFS Northeast Regional Administration. To provide guidance and co-ordination the NEFMC organized a Research Steering Committee (RSC) in 2000.

The project described in this report was vetted through the RSC and funded with a grant from NOAA administered by CRPI. The contents of this report comport with several research priorities identified by the Council/RSC and are intended to provide information of value to the advancement of understanding the impacts of specific types of mobile fishing gear on certain categories of EFH.

1.2 Project Goals and Objectives

The objective of our 2002 study was to provide targeted weekly trawling pressure (chronic impact) over a number of months on established experimental trawl corridors at two sites (Little Tow and Mud Hole) historically subjected to different trawling pressure in the Gulf of Maine off Scituate, MA. Replicate reference and experimental corridors at the two sites were sampled prior to trawling, and at two latter times during the chronic trawling to investigate any discernable cumulative impacts on the generally soft bottom habitat at the study areas.

A number of components of the 2002 study fell within the fisheries management information need. In particular,

(1) Conducting fishing industry-supported high-resolution sediment mapping in areas of the western Gulf of Maine (i.e. Little Tow and Mud Hole);

(2) Identifying biological communities (pelagic, epifaunal, infaunal) associated with the mapped areas and determining relationships between the soft bottom sediment type and these communities; and

(3) Examining and comparing commercially important fish species and benthic biological communities in soft bottom habitat in both heavily and lightly fished reference areas and how they respond to the cumulative impact of trawling with a smooth bottom trawl net.

More specific areas of investigation addressed by this report include:

- Ground truthing existing bathymetric and sediment maps of an area of EFH using side-scan sonar, video, precision bathymetric mapping, sediment profile imaging, and benthic sampling technologies;

- Observing acute and cumulative impacts of traditional soft bottom trawl gear, and monitoring these impacts over several months;

- Using statistical methods to correlate the degree of impact on benthic and demersal organisms between trawled and nearby untrawled ‘reference’ areas;

- Observation of fish and invertebrate species, particularly juvenile finfish, and their dependence on seabed structure for shelter; and

- Observation of the relative severity of impact attributable to the various components of the trawl gear system.

One of the primary goals of the 2002 repetitive trawling experiment was to provide meaningful data for long-term management of soft sediment ecosystems. The experimental treatment is designed to more closely resemble current trawling disturbance activity in intensity, as well as, spatial and temporal scope. In addition, this project should improve EFH designation in soft bottom habitat because it will help define soft sediment-prey field associations for managed groundfish species. Current EFH designations are based on presence/absence and relative abundance of each species from historical trawl survey data. Identifying substrate and prey species and their relationship to fish populations is one of the next logical steps in improving EFH designations.

1.3 Project Team

The project team included the same key personnel that participated in the 2001 trawl study "*Near Term Observations of the Effects of Smooth Bottom Net Trawl Fishing Gear on the Seabed*." (NOAA/NMFS 50-EANF-0-00061, October 2003) which included members of the south shore, Scituate, MA, fishing community and local consulting scientists with extensive experience working in the Massachusetts Bay region of the Gulf of Maine.

Mr. Francis Mirarchi, president of Boat Kathleen A. Mirarchi, Inc. and owner of the 62 ft inshore dragger F/V *Christopher Andrew*, was the prime contractor for the project and managed the fishing vessel activities. Other key fishermen involved in the project included Andrew Mirarchi, John Welch and John Shea owner of the 57 ft F/V *Yankee Rose* (Photograph 1.3-1 and 1.3-2).

CR Environmental, Inc. of Falmouth, MA, was the lead subcontractor managing field operations, data processing, and report preparation. CR Environmental, Inc. has worked closely with the New England fishing community for over 10 years. In 1995, CR was awarded a Fishing Industry Grant (FIG) to train fishermen in the conversion of their vessels for oceanographic research. One of this grant's training seminars was held in Scituate, MA and Mr. Mirarchi played a key role in recruiting fishermen for the project and provided the F/V Christopher Andrew for equipment demonstrations and training. Since that time the F/V Christopher Andrew and the F/V Yankee Rose and other New England fishing vessels chartered by CR Environmental have performed numerous research cruises from Maine to New York.

CR personnel supporting this NOAA Cooperative Research project included: John H. Ryther, Jr., oceanographic operations; Christopher Wright, biologist/hydrographer; Christopher Dunbar and F. Ray Shield, fisheries; and Charlotte Cogswell, ecologist.

Other key technical project personnel included David Stevenson Ph.D. now with NOAA/NMFS; Barbara Hecker Ph. D. of Falmouth, MA, an expert in the analysis of marine community structure and quantitative ecology; and Allan Michael Ph.D. of Magnolia, MA, a benthic infauna expert. For the 2002 study, two new team members played an integral part in the program. Science Application International Corporation (SAIC) based in Newport R.I. was subcontracted to perform Sediment Profile Camera (SPI) operations and analyze the SPI images. Raymond Valente was SAIC's chief scientist on the project. Donald Rhoads Ph.D. of Falmouth, MA, the inventor and leading expert in the SPI technology was brought in to review the SAIC data and other relevant trawl impact studies, and make recommendations for future studies.

1.4 Survey Gear Selection

The majority of survey and sampling equipment selected for the study is owned by CR Environmental and included:

- Dual frequency EdgeTech Model 272 TD *side-scan sonar* system consisting of an analog towfish with an ACI board, topside computer with digital interface, power supply, and Chesapeake Technology SonarWiz software and SonarWeb acquisition and processing software;

- SyQwest Bathy500 *precision echosounder* with a 3 degree narrow beam transducer

- Lightweight custom aluminum *towed video sled* with miniature Deep Sea Power & Light color video camera, video lights and navigation interface;

- Ted Young *benthic grab sampler* with a stainless steel frame, camera and light brackets, and stability fin;

- Seabird Seacat *CTD system* with a Seapoint OBS sensor ;

- Trimble AG132 *DGPS systems* with HYPACK survey software;

SAIC provided the Benthos Model 3731 *Sediment-Profile Camera System* to obtain the sediment profile images.

Additional oceanographic support equipment provided by BKAM and CR Environmental was fabricated by former Scituate, MA, fishermen, Bob Stevermen, and included an oceanographic winch, hydraulic A-frame, and side-mounted transducer boom.

1.5 Experimental Design

The cumulative impact of trawling with smooth bottom net trawl gear on soft bottom sea-floor characteristics and benthic communities was examined in two areas, “Mud Hole” and “Little Tow”, historically subjected to differing fishing pressure (Figure 1.0-1). Mud Hole is more intensively fished with mobile gear, and Little Tow has less mobile gear pressure due to its shape and size, and a high density of fixed gear (lobster traps and gill nets). For a more complete description of these study areas see our 2001 study at www.crenvironmental.NOAAtrawl.html.

Four non-overlapping, lanes or belt transects (1000 m x 100 m) were selected during our 2001 trawl study within each site: 2 experimentally trawled lanes and 2 temporal control (reference) lanes that were not experimentally trawled (Mud Hole - Figure 1.0-3, Little Tow - Figure 1.0-4). Survey and sampling operations were conducted at stations on each of the experimental and control lanes prior to the 2002 chronic experimental trawling to establish a baseline, and then once midway through the trawling (late September) and once at the end of the chronic trawling (November).

Baseline sampling at the study sites (Mud Hole and Little Tow) was conducted for all lanes prior to chronic trawling in July 2002 and during the two post-chronic trawling cruises in September/October and November 2002. Data collected included:

- 500 kHz side-scan sonar along the experimental trawl and control lanes;
- Video footage along transects approximately one hundred meter long and run perpendicular to the experimental and control lanes at 12 stations to obtain detailed video coverage for viewing biota and physical trawl impacts;
- Three replicate benthic grab samples at 8 selected stations per cruise for infaunal characterization for a total of 72 samples over the study; and one grab for sediment grain size analysis at the same 8 stations per cruise for a total of 24 samples over the course of the study;
- CTD casts at each of the 12 sampling stations per cruise;
- Three replicate SPI camera drops at 12 stations for a total of 108 images;
- Experimental fishing trawls and the collection of flatfish stomachs was performed along the trawled lanes on each of the three cruises.

Table 1.5-1 Sampling Design

SITE	MUD HOLE				LITTLE TOW			
Transects	Experimental		Control		Experimental		Control	
PRE CHRONIC TRAWLING July 2002	Lane 1	Lane 3	Lane 2	Lane 4	Lane 1	Lane 3	Lane 2	Lane 4
500 kHz side-scan	1	1	1	1	1	1	1	1
Video sled crosstie	1	2	1	2	1	2	1	2
Benthic infaunal samples (3 replicates)	1	1	1	1	1	1	1	1
Grain size samples	1	1	1	1	1	1	1	1
CTD	3	3	3	3	3	3	3	3
SPI	3	3	3	3	3	3	3	3
Experimental Trawls and Flatfish stomachs	1	1			1	1		
POST CHRONIC TRAWLING Sept/Oct 2002	Lane 1	Lane 3	Lane 2	Lane 4	Lane 1	Lane 3	Lane 2	Lane 4
Prior Trawls	13	13			13	13		
500 kHz side-scan	1	1	1	1	1	1	1	1
Precision Bathymetry	1	1	1	1	1	1	1	1
Video sled - CT	1	2	1	2	1	2	1	2
Benthic infaunal samples (3 replicates)	1	1	1	1	1	1	1	1
Grain size samples	1	1	1	1	1	1	1	1
CTD	3	3	3	3	3	3	3	3
SPI	3	3	3	3	3	3	3	3
Experimental Trawls and Flatfish Stomachs	1	1			1	1		

POST CHRONIC TRAWLING Nov 2002	Lane 1	Lane 3	Lane 2	Lane 4	Lane 1	Lane 3	Lane 2	Lane 4
Prior Trawls	20	20			20	20		
500 kHz side-scan	1	1	1	1	1	1	1	1
Video Sled- CT	1	2	1	2	1	2	1	2
Benthic infaunal samples (3 reps)	1	1	1	1	1	1	1	1
Grain size samples	1	1	1	1	1	1	1	1
CTD	3	3	3	3	3	3	3	3
SPI	3	3	3	3	3	3	3	3
Flatfish Stomachs	1	1			1	*		
Experimental Trawling	1	1			1	*		

* No experimental trawl sample due to excessive fixed gear in the lane.

2.0 CUMLATIVE TRAWL IMPACT STUDY FIELD OPERATIONS AND METHODS

2.1 Navigation Methods

Navigation for the survey operations were performed using each ship's Differential Global Positioning System (DGPS) or outfitting the vessels with a Trimble AG132 DGPS accurate to within 1 meter. These systems were interfaced to a laptop computer loaded with Hypack survey software. Identifying coordinates for the start and end points and random sampling stations along the study lanes were logged.

2.2 Trawl Methods

Trawling was conducted only on the experimental Lanes 1 and 3 at the Mud Hole and Little Tow sites. Trawl passes were made approximately weekly for a total of 18 impact events and during three experimental survey operations: one pre-chronic impact survey event on August 2, 2002 and two surveys during the chronic trawling in October and November 2002).

2.2.1 Impact trawling

On August 2, and October 7, 2002, experimental trawling operations were performed from the 65 ft F/V *Christopher Andrew* at Mud Hole and Little Tow. Twelve chronic trawl impact episodes were conducted aboard the 58 ft F/V *Yankee Rose* between August 2 and September 30, 2002. Following the survey operations and experimental trawling of September 30 through Oct 10, 2002, six more chronic trawl impact episodes were performed. On November 9, 2002, similar experimental trawling operations were performed from the F/V *Yankee Rose*. Due to the presence of lobster gear at Little Tow Lane 3 it was not trawled on November 9, 2002. Overall, the gear used by the two boats was similar, and it is assumed that they were equally efficient.

Each trawl episode consisted of a single pass on the experimental lanes 1 and 3 at Mud Hole and Little Tow. Completing the four tows and managing the catch along a lane during the experimental trawls took on average about a day (Photograph 2.2-1). The cod end of the smooth bottom trawl net was outfitted with a 3-inch mesh liner to retain juvenile fish, and the vessels were operated under an experimental fisheries permit. Towing speed was approximately 3 knots. David Stevenson, Ph.D. and Chris Dunbar made up the scientific crew, and were supported by the vessel owner, Frank Mirarchi, and a two-man ship's crew.

The otter trawl of the two boats consisted of the following components:

F/V *Yankee Rose*

- Doors- Bison Type Steel, Polyvalent, L 68" X 44", Est. weight 300 kg
- Ground Cables-2.5 " O.D. Rubber Discs ("Cookies") Strung on 5/8" Steel Cable. LOA=240 ft (est. weight of wire 1 lb/ft)

- Legs- Lower- 3/8" Trawlex chain (est. wt 2lbs/ft)
  Upper- ½" steel cable
  LOA of legs = 30ft

- Sweep- 5" rubber discs strung on ½" Trawlex chain (est. wt. 3lbs/ft)
  LOA of sweep = 90'

- Net Headrope- 66' of 5/8" combination wire (steel + poly fiber). 11-8" diameter Aluminum or plastic floats (5-6 lbs buoyancy/float)

- Footrope – 90' ¾" Poly rope

- Netting- 6" (160mm) X 3mm Polyethylene fishing circle 270 meshes

- Cod End-6 ½ " (180mm) Double 4mm Polyethylene 50 bars circ. X 50 bars depth

- Net and Liner Mesh - The mesh of the net was 6 inches, and a 3 inch smaller mesh panel lined the cod end to retain juvenile fish.

F/V *Christopher Andrew*

- Doors- Thyboroon Type Steel, Polyvalent, L 66" X 48", Est. weight 325 kg

- Ground Cables-3 " O.D. Rubber Discs ("Cookies") Strung on 3/8" Steel Chain.
  LOA=240 ft

- Legs- Lower- 3/8" Trawlex chain (est. wt 2lbs/ft)
  Upper- ½" steel cable
  LOA of legs = 30ft

- Sweep- 5" rubber discs strung on ½" Trawlex chain (est. wt. 3lbs/ft)
  LOA of sweep = 88'

- Net Headrope- 66' of 5/8" combination wire (steel + poly fiber). 21-8" diameter Aluminum or plastic floats (5-6 lbs buoyancy/float)

- Footrope – 90' Rubber "snowman" on 3/8" wire

- Netting- 6" (160mm) X 4mm Polyethylene fishing circle 270 meshes

- Cod End-6 ½ " (180mm) Double 4mm Polyethylene 50 bars circ. X 50 bars depth

- Net and Liner Mesh - The mesh of the net was 6 inches, and a 3 inch smaller mesh panel lined the cod end to retain juvenile fish.

Each trawl catch was sorted and weighed by species. Stomachs were removed from up to 10 individuals of 3 bottom-feeding target species (winter flounder, yellowtail flounder and cod) from each tow and preserved individually in 10% formalin. Following transfer from formalin to alcohol the collections of individual flatfish stomachs for each sample (i.e. fish species by tow date, study site, and trawl lane) were presorted by trained fishermen into vials for annelids, crustaceans, molluscs, miscellaneous taxa and unidentifiable (partly digested) material at BKAM in Scituate, MA. Sorted stomach contents were identified to the nearest taxa by Allan Michael & Associates Lab of Magnolia, MA. Total lengths in centimeters were recorded for all winter flounder, yellowtail flounder and Atlantic cod (Photograph 2.2-2). Weight per tow for the most common species were converted to densities (kilograms per 1000 square meters) by estimating the area swept during each tow and assuming that all organisms in the path of the trawl were, in fact, caught. Commercially targeted flatfish numbers were also converted to densities (number per 1000 square meters) in a similar fashion. Densities were only estimated for bottom-dwelling finfish since mid-water species like spiny dogfish and herring are less vulnerable to capture in bottom trawls.

Neither mean weight estimates nor complete catch in numbers data were available for benthic macro-invertebrates (crabs, lobsters, and scallops), so they were not included either.

Area swept was calculated as:

$$\text{Area} = [(1/2\ (HL + FL))/2] \times TL$$

Where HL = headrope length, FL = footrope length (length of the sweep between the wings of the net, excluding the legs and ground cables that extend to the doors), and TL = tow length. For the bottom trawl used on the fishing vessels, the width of the net was 76ft or approximately 11.6 m. Although the trawl lanes were intended to be 1000 m long, actual tow lengths varied from 940m to 1292m and averaged 1141 m.

2.3 Water Column Sampling Methods

Water column characteristics were documented at the study sites, Mud Hole and Little Tow, during the experimental surveys on August 1, October 10, and November 12, 2002. CTD casts were made at the three sampling stations on Lanes 1 through 4 with a Seabird SBE-19 Seacat CTD Profiler equipped with oxygen and turbidity sensors. Recorded parameters included turbidity, temperature, dissolved oxygen, and salinity.

2.4 Bathymetric Surveys

During the June 2001 reconnaissance survey of the study sites, a wide area coverage *bathymetric survey* was conducted using the ship's DGPS and echosounder. The survey confirmed that the study sites, Mud Hole and Little Tow were in waters ranging from 120 to 140 ft in depth. During the 2002 trawl study, a more detailed precision bathymetric survey was conducted aboard the F/V *Christopher Andrew* on September 30, 2002. The bathymetric survey was conducted by navigating along 20 planned survey transit lines, spaced 50-meters apart and oriented parallel to the lanes at Mud Hole and Little Tow. A Differential Global Positioning System (DGPS) and echosounder were interfaced to a shipboard computer running Coastal Oceanographic's HYPACK hydrographic surveying software. During the survey, HYPACK calculated meter scale XY positions, recorded the depth and navigation data, and provided a steering display for the vessel helmsman.

Real-time horizontal position accuracy of less than 1-meter was achieved using a Trimble DGPS Navigation AG132. United States Coast Guard differential correction beacons were used to provide real-time corrections to satellite data. DGPS signal quality and satellite geometry were continuously monitored during the survey.

Water depth measurements were collected using an ODEC 500-MF precision echosounder. The echosounder was equipped with a 3-degree 200-kHz transducer with an accuracy of 0.5% of the indicated depth. The echosounder output depth measurements at a rate of between 2 to 10 soundings per second, depending on water depth. Profiles of temperature and salinity at the survey sites were generated using a Seacat SBE-19 CTD. These data were used to adjust soundings for subtle variations of sound velocity with depth.

Raw (unaltered) bathymetric data for each transect line were evaluated using Hypack's editing routine. Outlying data points (spikes) caused by biological interference (e.g., pelagic fish) were deleted. Corrections for tide and sound velocity were applied. Bathymetric data were corrected for in-situ sound velocity using profile data obtained from CTD casts. Tide corrections were applied to the data using the NOAA 6-minute tide series for Boston Light (MLLW). Data were exported from Hypack as a comma-delimited ASCII file. All data were converted to the metric Massachusetts Mainland State Plane grid, referenced to the North American datum of 1983.

Grids of seabed elevations were produced by importing bathymetric data to Surfer for Windows (V. 8.0, Golden Software, Inc.). Kriging interpolation methods were used to calculate a dense grid network (i.e. 3-dimensional surface) representing the survey data sets. Maps depicting the bottom elevation at 1.0-foot intervals were produced using the resulting grids. The maps were exported as Drawing Exchange Format (DXF) files suitable for use with GIS and CADD software. The DXF file was imported to ArcView V. 3.2a GIS software.

2.5 Side-scan Sonar Methods

High resolution side-scan sonar operations were performed on July 29, 2002 before trawling and on September 30 and November 20, 2002 after chronic trawling at Mud Hole and Little Tow. At each site, the side-scan fish was run along the two experimentally trawled lanes and the two control lanes. The purpose of the side-scan surveys was to gather information on the character of the bottom substrate and to look for evidence of project related trawl impacts on the experimental lanes; and document physical changes to the seabed over the course of the four-month study. Surveys were performed with an Edgetech 272 TD towfish and the Chesapeake Technology Sonar Wiz data collection software (Photograph 2.5-1 a-c). The side-scan system was operated at the 50-m range scale and the 500-kHz frequency, and the side-scan towfish was towed 5 to 10 meters off the bottom. Operations were conducted from the 62-ft F/V *Christopher*

Andrew captained by owner Frank Mirarchi and a one-man crew. The *Christopher Andrew* was outfitted with a hydraulic winch with a 200 m length of multi conductor coax cable and a slip ring assembly that could support both the side-scan and underwater video sled operations. The scientific crew responsible for side-scan operations included John Ryther, Jr. and Christopher Wright.

High frequency *side-scan images* for the baseline survey and post chronic trawl surveys of the eight study lanes (4 control and 4 trawled) were processed using Chesapeake Technology, Inc.'s SonarWeb software. Accurate layback from the DGPS antenna to the towfish was calculated and beam-angle corrections were made to each sonar file.

Both geo-referenced and non-projected sonar data were inspected. Non-projected high resolution "waterfall" side-scan imagery often provides valuable clearer bottom imagery. Geo-referenced side-scan sonar imagery was imported to ArcView GIS for detailed inspection. Data layers representing video drifts, grab samples and SPI observation points were added to the GIS project to aid interpretation.

2.6 Benthic Sampling Methods

Benthic infauna and sediment grain size samples were collected to determine the potential effects of trawling on the benthic invertebrate community that serves as prey for bottom feeding fish in the study area.

On July 31, 2002, pre-trawl benthic sampling was performed from the 62 ft F/V *Christopher Andrew*. Positioning during the benthic sampling operations was performed with a Trimble AG 132 DGPS and the HYPACK survey software. The scientific crew consisted of Allan Michael, Ph.D., Christopher Wright, and Chris Dunbar assisted by Frank Mirarchi, the vessel owner, and the fishermen Andrew Mirarchi and John Welch.

A 300-ft length of 3/8-inch wire was wound on the vessel's trawl winch and the grab sampler was deployed and recovered using the 20 ft high stern mounted A-frame. Bottom grabs were obtained with a 0.04 m^2 Ted Young modified van Veen grab sampler. Sampling was conducted at eight of the 24 stations along the control and trawled lanes established during the 2001 study. One station on each of the lanes was sampled (MH-1B, MH-2B, MH-3B, MH-4B and LT-1B, LT-2B, LT-3A, LT-4A). This subset of stations was chosen due to the similarity in their grain size. At each station, three replicate grabs were collected for the benthic community and one for grain size. Benthic samples were sieved using a 500 micron mesh sieve and stored in formalin. (Photograph 2.6-1 a-c).

Two post-chronic trawling benthic sampling efforts were performed on October 9 and November 19, 2002, from the F/V *Christopher Andrew.* During the October and November sampling efforts, a miniature underwater video camera, lights, and a stability fin were added to the Ted Young grab sampler to provide bottom video coverage prior to taking a sample. This video grab system was based on a design used by U.S.G.S. Video ensured that the benthic samples were collected in similar substrate and allowed for observation of any obvious trawl disturbance. The video grab system is pictured in Photograph 2.6-2. During the three sampling efforts, a total of 72 infauna samples and 24 grain size samples were obtained during the three benthic cruises.

The sieved and preserved benthic infauna samples were transferred from formalin to alcohol and dyed with rose bengal (a protein dye) for presorting by the fishermen. During the 2001 NOAA trawl study, fishermen Frank Mirarchi and John Shea, and CR personnel Chris Wright and Chris Dunbar received training in benthic presorting by Allan Michael, Ph.D. Infauna were sorted into vials for crustacea, annelids, mollusks and miscellaneous organisms. Sediment residue was saved and checked by taxonomists at Allan Michael & Associates, Magnolia, MA. Infaunal samples were identified to the lowest practical taxonomic unit and the results for each sample entered into an Excel database as quantitative units. Grain size samples were also processed at Allan Michael & Associates lab. Percent gravel, sand, silt and clay, and the median grain size were determined for each sample on a dry weight basis.

2.7 Sediment Profile Camera Methods

SAIC and CR personnel performed sediment profile camera operations on August 1, October 10 and November 12, 2002 aboard the F/V *Christopher Andrew*. The Benthos, Inc. Model 3731 SPI system was used for the study. The system consists of a large stainless steel frame with lead weights, a prism and faceplate, a passive hydraulic piston, and an electronics housing for a 35 mm camera. The Benthos SPI camera system weighs approximately 1000 pounds and was deployed and recovered using the stern A-frame and trawl winch on the Christopher Andrew (Photograph 2.7-1).

On each SPI cruise, the Ektachrome 35m film was developed onboard the vessel using the E-6 developing process to ensure that good photographs were obtained at all the sampling stations. At the Mud Hole and Little Tow sites, triplicate camera drops were performed at all 24 sampling stations along the control (12 stations) and experimental trawl lanes (12 stations) for a total of 72 images per survey effort. SPI images were analyzed by SAIC scientists, Ray Valente and Natasha Pinckard, and the results reviewed by Don Rhoads, Ph.D. Standard methods for the collection and analysis of the Remots sediment profile images are provided in Appendix 2.7-A.

2.8 Video Sled Methods

The video sled system consists of a lightweight aluminum frame that is equipped with a portable high resolution Deep Sea Power and Light color video camera, two Deep Sea Power and Light 250 watt lights and a navigation interface system. During the 2002 study, the sled was lowered to the bottom using an oceanographic winch equipped with a slip ring assembly and an armored communication cable (Photograph 2.8-1 a-c). Video images were monitored throughout each transect and the amount of wire out was continually adjusted to maintain optimum viewing distances. The video sled is a simple system that is fast and easy to mobilize and operate. This was particularly critical because the study design consisted of three cruises with a limited amount of ship time. The 2001 study utilized a combination of a Benthos Mini-Rover remote operated vehicle (ROV), and a video-sled run in both towed (1 to 2 knot speed) and drift (0.5 to 1 knot speed) modes. Of these methods, the ROV footage provided the best images of the impact of trawling on the seafloor, and the cross transect drifts were found to provide better quality video for discerning the physical impacts of the trawl gear. The video-sled drifts for this 2002 study were performed in an attempt to mimic the speed and height off the bottom of the ROV in the 2001 study. With three separate cruises and one day budgeted per cruise for video operations, the cost of using the ROV for the 2002 trawl study was not viable. Instead, CR's underwater video sled was used to provide comparable underwater video coverage during the 2002 study.

Video-sled transects of approximately 100-meter length were run perpendicular to the control and trawl corridors at 12 stations, 6 in Mud Hole and 6 in Little Tow. The transects were run at each of the following sites: MH-1B, MH-3A, MH-3B on trawled lanes, MH-2B, MH-4A, MH-4B on control lanes, LT-1B, LT-3A, LT-3B on trawled lanes, and LT-2B, LT4A, LT-4B on control lanes. This resulted in 3 experimental and 3 control areas surveyed at each location. These sites were a subset of the original 24 benthic and ROV stations occupied during the 2001 study.

The pre-chronic trawling video sled survey was performed on July 30, 2002 and the two post-chronic trawling surveys were performed on October 2, and November 20, 2002. The video-sled operations were performed off the F/V *Christopher Andrew* operated by Frank and Andrew Mirarchi. The scientific crew for video operations included Christopher Wright, John H. Ryther, Jr. and Barbara Hecker, Ph.D. (Photograph 2.8-2 a-c). The video transects were conducted by towing the sled slowly (0.5 to 1 knot) along the bottom with the ship at clutch speed or drifting. Vessel speed was slowed to acceptable levels by using a drogue buoy. Trawl marks from the doors and sweep of the net were readily detected during the 2001 ROV transects and the cross-sectional video sled drifts. However in 2002, bottom water visibility was extremely poor during all three cruises, with high amounts of suspended material throughout the water column. Although numerous door marks were detected at the trawl lanes with the side-scan sonar, no trawl marks were observed with the video sled. Due to the poor visibility, sea floor imaging required angling the video sled downward and maintaining the camera 0.5 to 1 ft off the bottom. With the camera this close to the bottom, it was impossible to maintain proper light intensity, which also compromised the quality of the video footage. Due to the poor visibility encountered in 2002, utilizing the ROV in 2002 would not have substantially improved the quality of the images. Video images and audio narration were recorded during each of the cross transect drifts on videotapes and DVDs, and brought back to the laboratory for analysis.

The video sled footage was viewed on a large projection screen by a team of two people. All organisms were counted and identified to the lowest possible taxonomic designation. Based on “voucher” specimens collected in 2001, the white seastar consisted of two species, *Asterias vulgaris* and *Leptasterias tenera*. Juvenile *A. vulgaris* could not be reliably discerned from *L. tenera* on the video footage, so the two species were lumped into the general sea star category. Representative video screen captures of the underwater footage were created using POWERDVD software.

2.9 Cruise Summary

A summary of the cruise activities for the 2002 NOAA Trawl Study is presented below:

<u>July 2002 Pre-chronic Trawling Cruise (July 29 to August 2)</u>

In July 2002, a five-day pre-trawl cruise was performed on the F/V *Christopher Andrew* from July 29 to August 2 and the following activities were performed.

1. (7/29/02) 500 kHz side-scan at control and experimental trawl lanes at Mud Hole and Little Tow.

2. (7/30/02) 15 minute video tows - 6 stations MH, 6 stations LT for a total of 12 drifts.

3. (7/31/02) Triplicate benthic grabs - 4 stations at MH and 4 stations at LT for a total of 8 stations x 3 reps for a total of 24 samples.

4. (8/1/02) SPI (sediment profile imaging) 3 replicates taken at 12 benthic stations in MH and LT (sampled in 2000) for a total of 24 stations sampled

5. (8/2/02) Fisheries survey trawling performed at MH-Lane1, MH-Lane 3, LT-Lane 1, and LT-Lane 3

<u>August/September First Round Impact Trawling</u>

During the months of August and September - 12 days of impact trawling was conducted along the experimental trawl lanes 1 and 3 at Mud Hole and Little Tow with the F/V *Yankee Rose*

<u>September/October First Post-Chronic Trawling Cruise (September 30 - October 10)</u>

1. (9/30/02) 500 kHz side-scan at control and experimental trawl lanes at Mud Hole and Little Tow

2. (9/30/02) Precision bathymetric survey at MH and LT

3. (10/2/03) 15 minute video tows at 6 stations in MH, 6 stations in LT for a total of 12 video drifts

4. (10/7/02) Trawling performed at MH-Lane 1, MH-Lane 3, LT-Lane 1, LT-Lane 3

5. (10/9/02) Triplicate benthic grabs at 4 stations in MH and 4 stations in LT for a total of 8 stations and 24 samples

6. (10/10/02) SPI 3 reps at 12 benthic stations in MH and LT for a total of 24 stations

<u>October/ November Second Round Impact Trawling</u>

Six additional days of impact trawling with the F/V *Yankee Rose* for a cumulative total of 20 days of trawl impact on the experimental lanes (1 – baseline experimental July, 12 impact trawls Aug/Sept, 1-Oct post-trawl experimental, 6 impact trawls Oct/Nov)

November Post-Chronic Trawling Cruise - 4 days (November 9 through 20th)

1. (11/9/02) Experimental Trawling F/V *Yankee Rose* at MH-Lane1, MH-Lane 3, and LT- Lane 1 (LT-Lane 3 could not be trawled due to the presence of a large amount of fixed gear)

2. (11/12/02) SPI camera 3 reps at 12 stations MH and LT for a total of 24 stations

3. (11/19/02) Triplicate benthic grabs at 4 stations at MH and 4 stations at LT for a total of 8 stations x 3 reps or 24 samples.

4. (11/ 20/02) 500 kHz side-scan at experimental and control lanes 4 transects; twelve 15 minute cross transect video drifts, 6 at MH and 6 at LT for a total of 12 video drifts

3.2 Geophysical Results

The study sites Mud Hole and Little Tow as described in our 2003 NOAA report, "*Near Term Observations of the Effects of Smooth Bottom Net Trawl Fishing Gear,*" are approximately 10 km offshore of Scituate, MA, south of Boston. Mud Hole, the slightly deeper and larger outer basin, has more soft sediment. The slightly shallower and narrower Little Tow basin appears a higher energy environment with coarser, sorted material. During major winter storm events, energy from large swells penetrate deeply enough to disturb the substrate of both basins. The sections that follow describe in detail the results from a more detailed bathymetric survey conducted in September 2002 and substrate characteristics detected by side-scan sonar and grain size analysis before (July 2002) and after chronic trawling (October and November 2002) in the study sites Mud Hole and Little Tow.

3.2.1 Bathymetric Results

Figures 3.2.1-1 and 3.2.1–2 are bathymetric surface maps of Mud Hole and Little Tow, respectively. Depths at Mud Hole ranged from 119.5 to 142.7 ft below Mean Lower Low Water (MLLW). The mean depth was 136.2 ft below MLLW. Mud Hole slopes from north to south and the majority of the site contains very little relief. The northern portions of Lanes 1 and 2 are located on a gradual slope (approximately 7 ft change in elevation over 1,000 ft) that originates at a rock outcrop to the north. Sample station MH-1A is located on the lower portion of this slope, and Stations MH-1B, MH-2A and MH-2B are near the toe of this slope. The remaining sample stations were on relatively flat portions of the seafloor.

Depths at Little Tow ranged from 113.7 to 126.8 ft below MLLW. The mean depth was 121.2 ft, fifteen feet shallower than the mean depth of Mud Hole. The terrain of Little Tow was more irregular than that of Mud Hole. A shallow depression is located along the northern portions of Little Tow Lanes 1 and 2. Sample station LT-2A was located within this depression. Another larger depression was observed at the northern end and immediately east of Lane LT-4. Sample station LT-4A was located within this depression.

3.2.2 Side-Scan Sonar Results

The late July pre-chronic trawling, and September and November 2002 post-chronic trawling side-scan sonar surveys were conducted in order to:

(1) Map the presence of project-related gear disturbances on trawled lanes;

(2) Confirm the absence of project-related gear disturbances on control lanes;

(3) Document non-project related background disturbances associated with commercial fishing; and

(4) Document physical changes to the seabed over the course of the four-month study.

Both non-projected 'raw' sonar data and geographically referenced data were inspected to meet these goals. Geo-referenced side-scan sonar imagery was imported to ArcView GIS for detailed inspection. Data layers representing video drifts (Section 3.3), benthic grab samples (Section 3.4) and SPI observation points (Section 3.5) were added to the GIS project to aid interpretation. The high-resolution non-projected "waterfall" side-scan imagery often provides clearer bottom imagery, and was closely inspected.

Side-scan sonar data is typically depicted as a range of grey shades that correspond to the strength of the returning acoustic signal. The eye can perceive a wider range of color shades than grey shades (Fish & Carr, 2001). Recognition of targets and fine bottom features in sonar data may be facilitated by inverted colorized data displays. A key to the shading and color ranges employed for this trawl surveys are provided below.

Index to Sonar Image Color Scales

Sonar shadow------------ Weak Signal Return----------------------------Strong Signal Return

In general, weak signal returns correspond to:

- smooth seabed substrates (e.g., fine sediments with little microtopography),
- to soft materials that absorb the signal, or
- to a seabed sloping away from the signal source (towfish).

Strong signal returns correspond to:

- rough seabed substrates (e.g., gravel, cobble),
- highly reflective materials, or
- to a seabed sloping towards the signal source.

Features that rise above the seabed (e.g., boulders) reflect more of the sonar energy than the surrounding substrate resulting in strong signal returns due to decreased angle of incidence. These features often prevent insonification of the area opposite the signal source, resulting in a sonar "shadow". See Figure 3.2.2-1 on the following page for an example of shadowing behind the peaks of sand waves. The length of these shadows can often be used to calculate the approximate height of the elevated features.

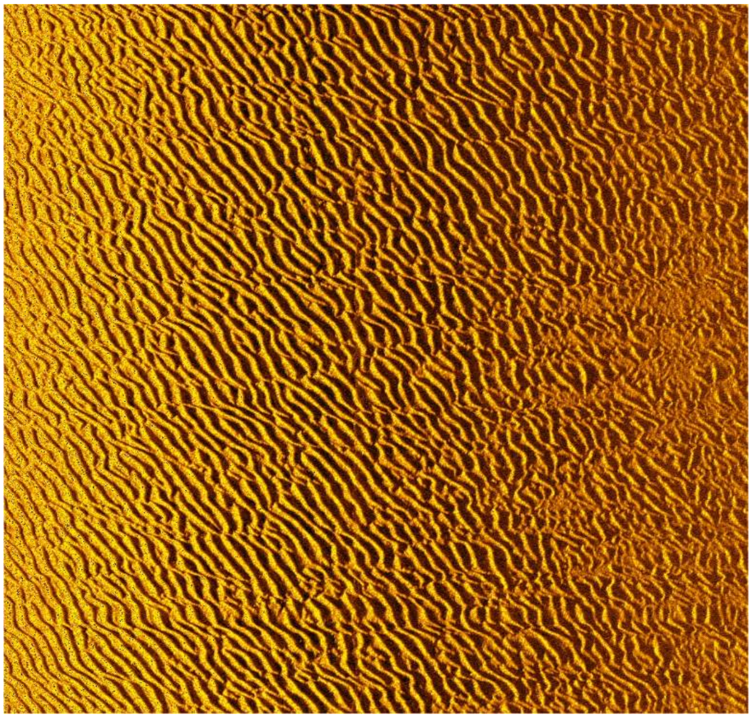

Figure 3.3.2-1 – Example of sonar shadowing behind the peaks of sand waves

The following sections detail sonar seabed observations for each of the study lanes (2 control and 2 trawl lanes at Mud Hole and Little Tow, respectively). To facilitate documentation of project-related changes, time-series figures were prepared for each of the eight 2002 benthic grab locations (see Time Series Figures in Appendix 3.2-A). These side-scan images from July, October, and November 2002 are centered on the grab sampling station, and depict geo-referenced sonar imagery for each of the three surveys at *approximately* the same location (image projections are slightly different due to inaccuracy associated with layback calculations). Additional figures of sonar imagery (both waterfall and geo-referenced) were prepared to document seabed conditions along other portions of the survey lanes.

3.2.2.1 Pre-chronic trawling side-scan survey results

Evidence of bottom fishing activity was observed on the July 29, 2002 side-scan sonar records for each of the eight survey lanes (MH-1, -2, -3, and -4 and LT-1, -2, -3 and -4). Note that Mud Hole and Little Tow lanes 1 and 3 were experimentally trawled in our 2001 acute impact study. In July 2002, control lanes (i.e. reference lanes) also showed signs of bottom fishing impacts. The dimensions of these fishing artifacts on the sonar records suggest that study lanes were impacted by otter trawl and scallop dredge gear (see Figure 3.2.2.1-1 on the following page).

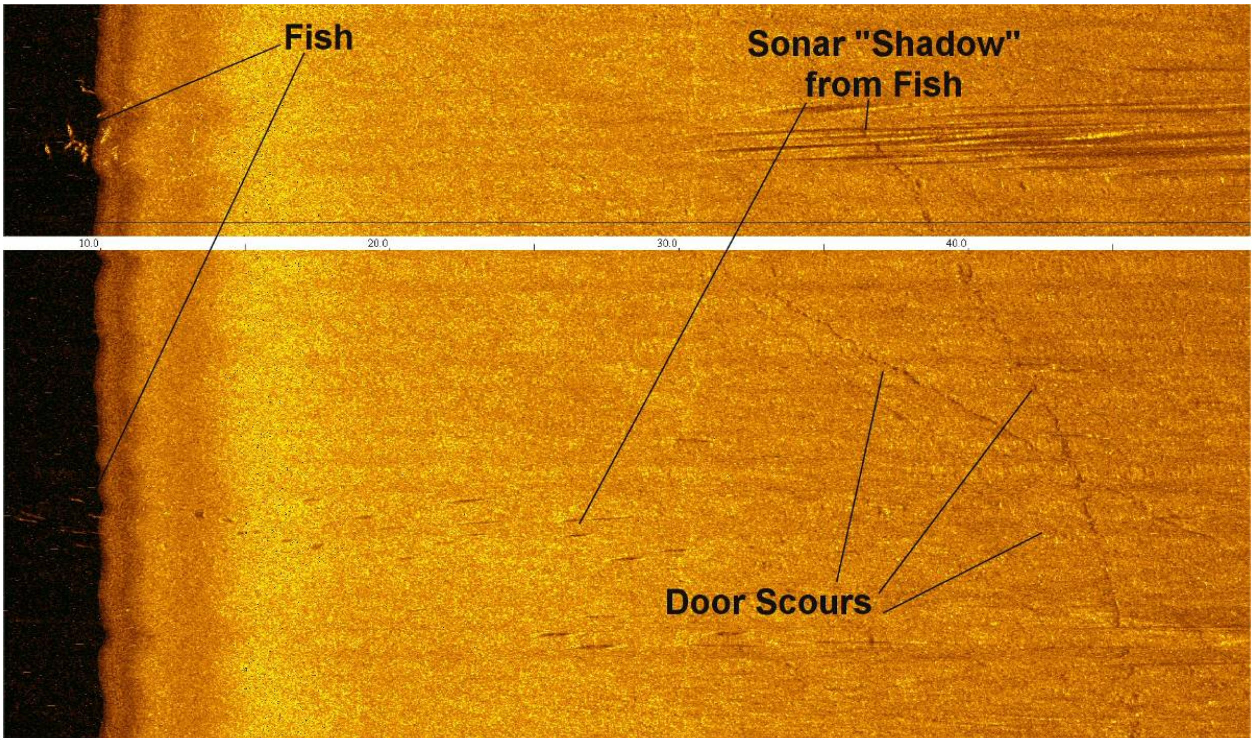

Figure 3.2.2.1-1 Bottom disturbances and fish observed along Mud Hole lane 3 in late July 2002 prior to chronic trawling

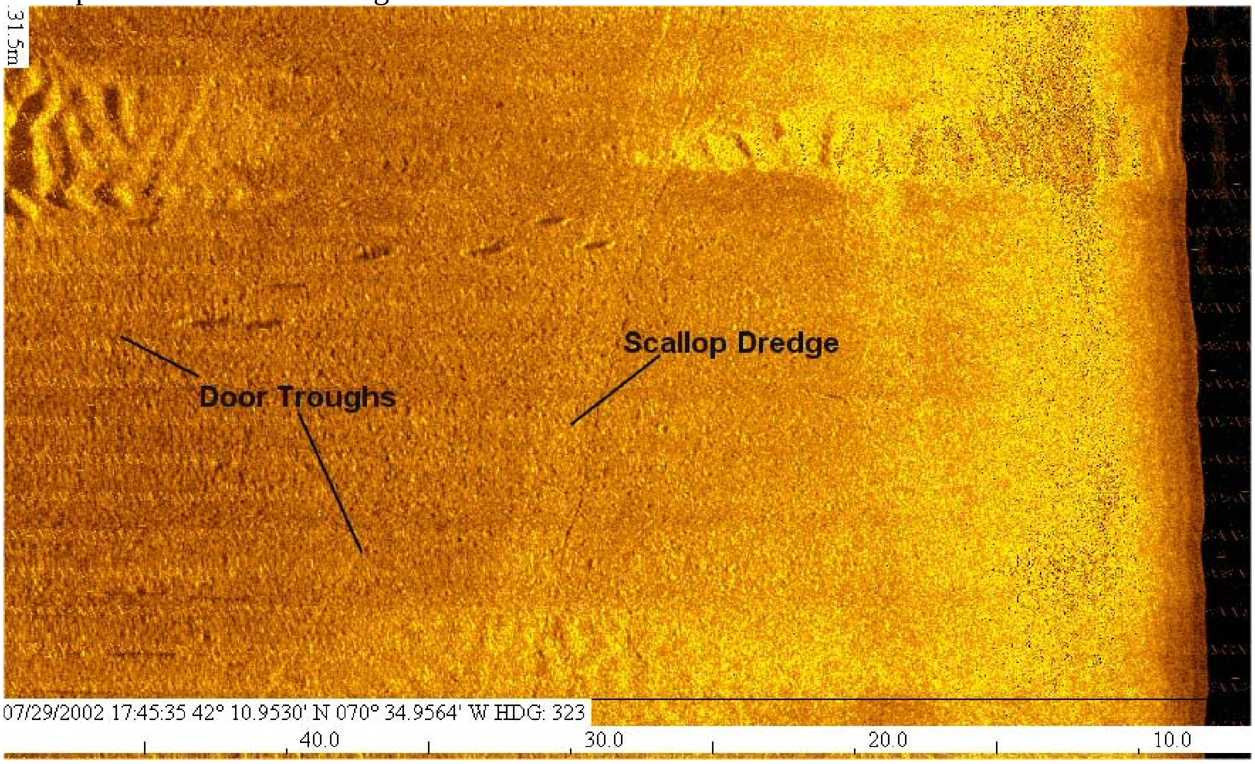

Figure 3.2.2.1-2 Bottom disturbances observed on Little Tow lane 1 in late July 2002 prior to chronic trawling

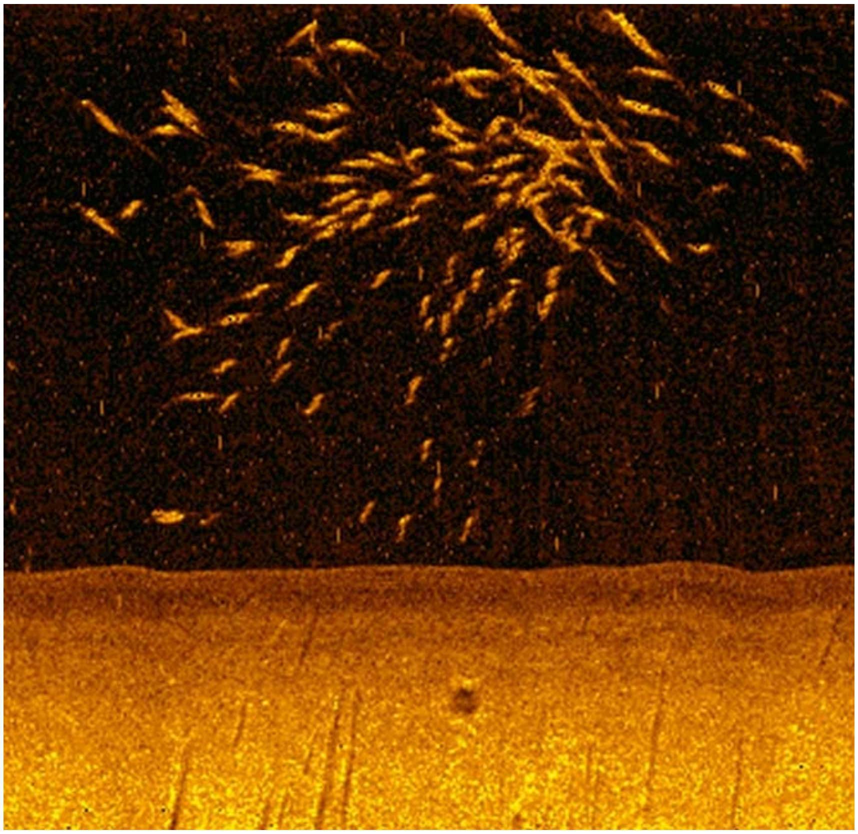

Figure 3.2.2.1-3 School of fish observed on Mud Hole lane 3 prior to chronic trawling

Figure 3.3.2.1-4 Sand waves on Little Tow lane 3 in July 2002 prior to chronic trawling

3.2.2.2 September 30, 2002 side-scan sonar survey results

In September 2002, following 13 tows over the experimental trawl lanes, bottom features associated with the experimental trawling were widespread on lanes 1 and 3 of Mud Hole and Little Tow (Figures 3.2.2.2-1 through 3.2.2.2-4). Based on the orientation of bottom scours it was often possible to differentiate between impacts due to the experimental trawling and impacts associated with commercial fishing. Project-related trawls were parallel to the experimental lanes and background trawls were not. Gear impacts were observed on sonar data collected along control lanes 2 and 4 at each area, but were limited to the western portion of the records. Sonar data suggests that experimental trawling operations did not directly impact the study sites' control lanes.

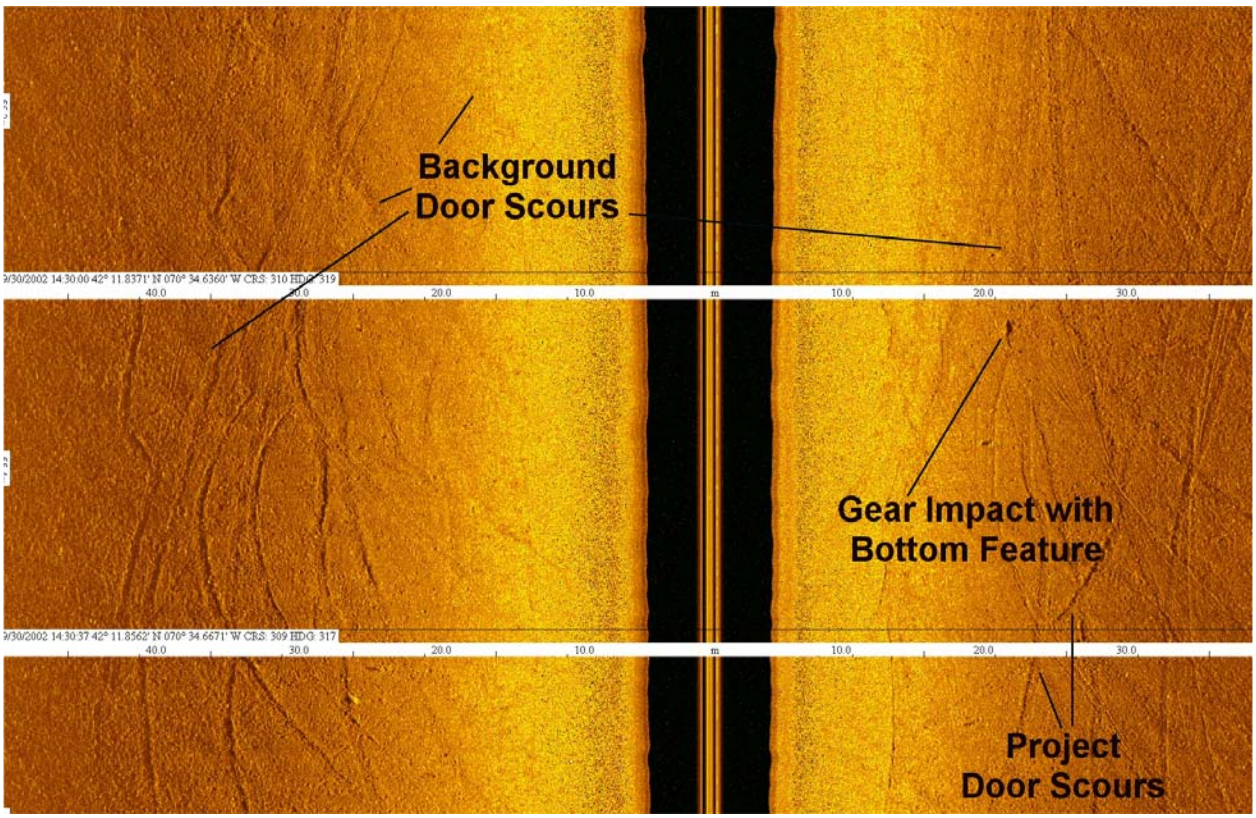

Figure 3.2.2.2-1 Background and project-related door scours observed at Mud Hole lane 1 in September 2002 following 13 trawls

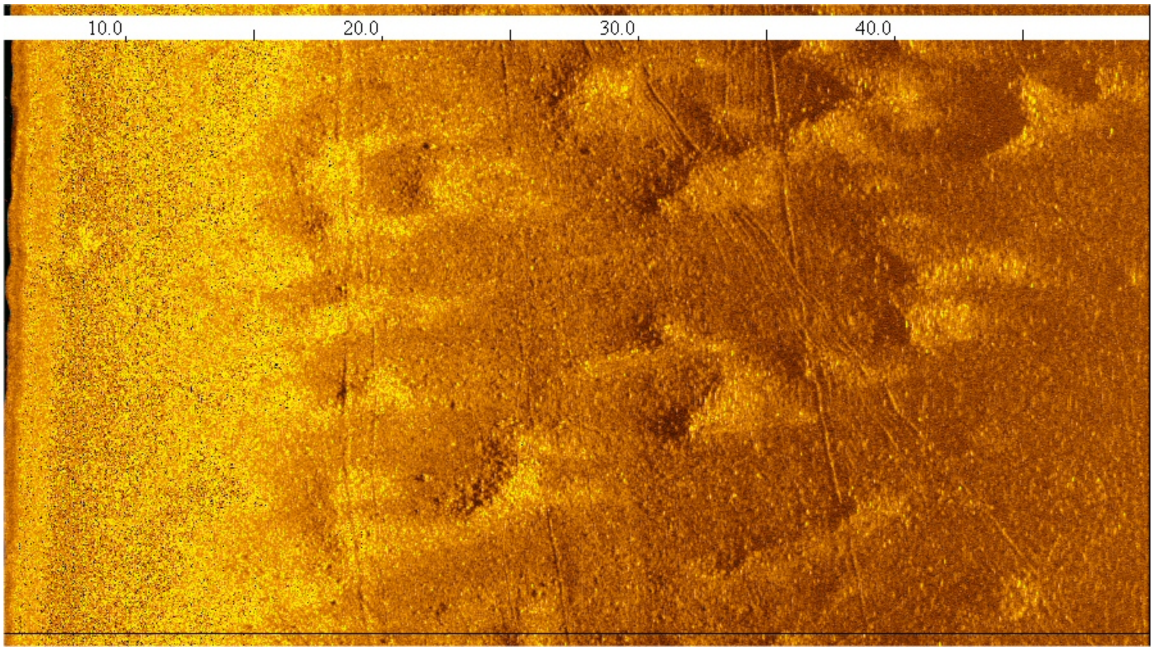

Figure 3.2.2.2-2 Mud Hole lane 1 September 2002 scours in hummocky sand

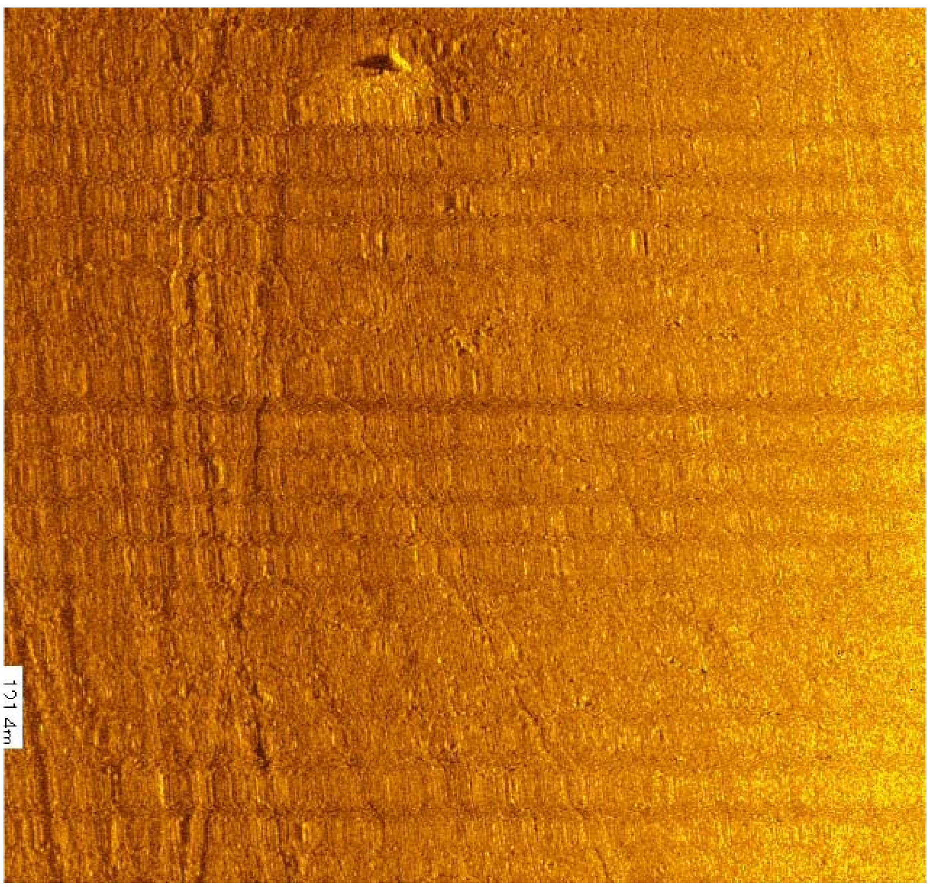

Figure 3.2.2.2-3 Door scours observed at Little Tow lane 1 in September 2002 following chronic trawling

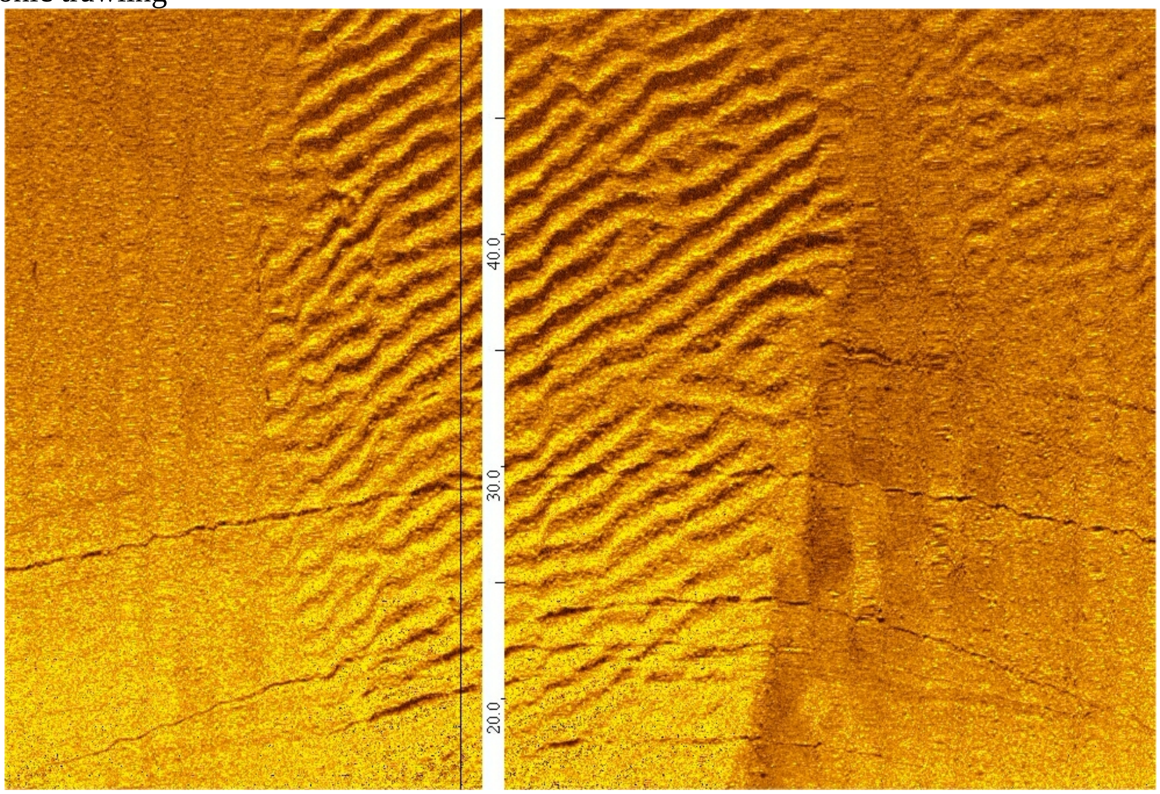

Figure 3.2.2.2-4 Little Tow experimentally trawled lane 3 September scours from chronic trawling and sand waves

3.2.2.3 November 20, 2002 side-scan sonar survey results

Sonar data for the final post-trawl survey in November of 2002 is particularly interesting and valuable because the survey was conducted shortly after a severe storm. The storm began on November 16th and subsided by November 19th based on meteorological and oceanographic data recorded by the NOAA Boston Buoy 44013. The maximum significant wave height was 5.6 meters, recorded at 4 p.m. on November 17th. This was the highest significant wave height recorded from January 1st to November 20, 2002 (Figure 3.2.2.3-1). Significant wave heights greater than 3.0 meters were recorded for 37 consecutive hours.

The effect of this storm on the seabed was substantial and obvious on the sonar records. In areas characterized by fine muddy sand substrates i.e. Little Tow lanes 1 and 2, and all of Mud Hole, the storm appears to have eroded widespread shallow depressions (Figure 3.2.2.3-2; Appendix 3.2-A Figure TS-10)). The formation of these depressions was particularly noticeable along the courses of trawl scours. This suggests that *these door scours, which September 2001 sonar and video observations indicate had clearly defined edges, were softened and expanded by the November 2002 storm-related currents. Some of these new features may represent areas where finer material had accumulated in depressions and subsequently been swept away by storm-related currents.*

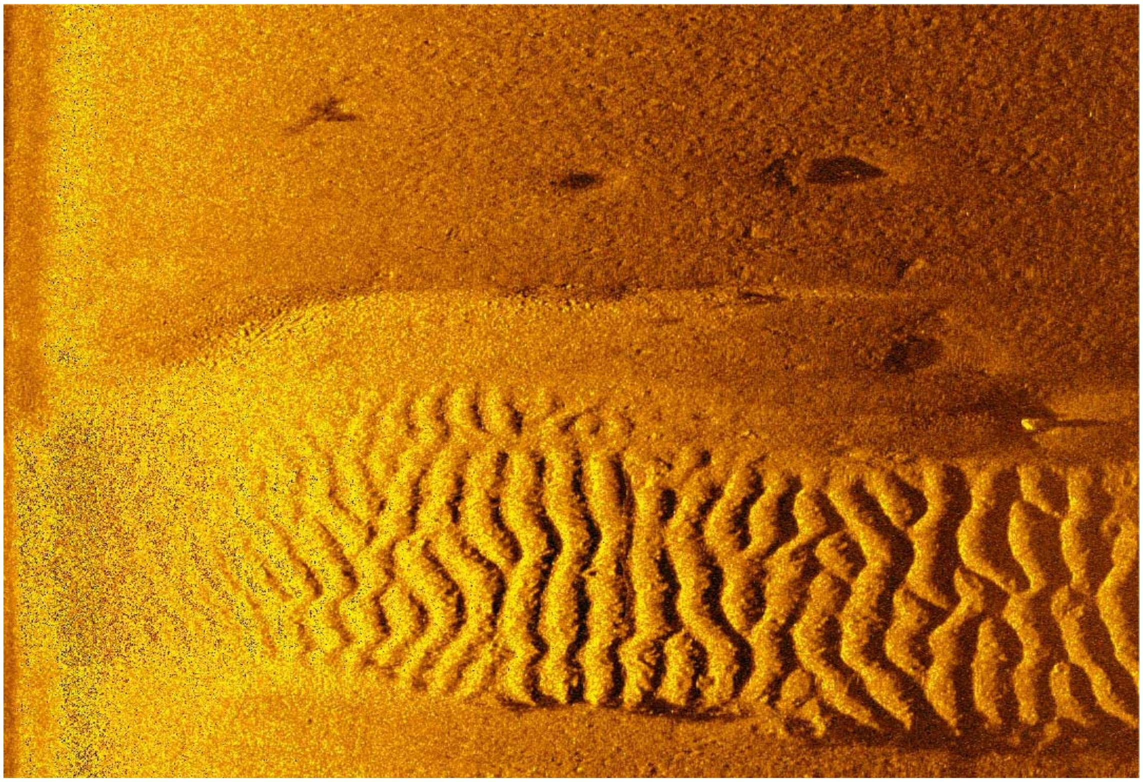

Figure 3.2.2.3-2 Little Tow lane 2 November 2002 sand waves and scour

In areas with coarser sand substrates, such as Little Tow lanes 3 and 4, the effect of the storm was more dramatic. Along Little Tow lanes 3 and 4, a 765-meter long field of sand waves replaced the relatively flat sandy bottom documented in July and September (see Appendix 3.2-A Figure TS-9). The wavelength of these sand waves was fairly uniform at approximately 70-centimeters. The ridge orientation of the waves was northwest/southeast, roughly parallel to the dominant wind direction during the November 2002 storm (~40 degrees), and *highlights the extensive impact of wind and wave action during storm events on the benthos in the shallower fishing ground of Little Tow.*

3.2.2.4 Time-series sonar observations at benthic grab stations

The following is a review of the side-scan sonar images for the paired control and experimentally trawled lanes at Mud Hole and Little Tow in the vicinity of the benthic grab stations for late July 2002 (pre-chronic trawling), and September and November 2002 (post-chronic trawling).

Mud Hole Observations:

Mud Hole Experimentally Trawled Lane 1 in the Vicinity of Station B

Mud Hole station MH-1B is located near the toe of a slope that rises gradually to the north (Figure 3.2.1-1). The substrate at this location appears to be relatively flat sandy mud. Pre-trawl sonar data for Mud Hole lane 1 shows widespread faint background gear impacts consistent with door marks. Background door marks were not observed in the vicinity of sampling station MH-1B.

Project-related trawl gear impacts were clearly visible on the September 30th and November 20th sonar imagery near station MH-1B. Background door marks observed during the pre-trawl survey remain visible on September 30th and November 20th images. These scours appear broader and less distinct in November compared to previous records likely due to sediment transport by bottom currents associated with the November storm. As shown on Figure 3.2.2.4 -1a and b (below) samples collected from station MH-1B in October 2002 extended into the western portion of the trawl lane which had been directly impacted by trawl doors. November samples from MH-1B were clustered around the planned lane centerline where trawl gear impacts likely consisted of chain and cookies of the sweep.

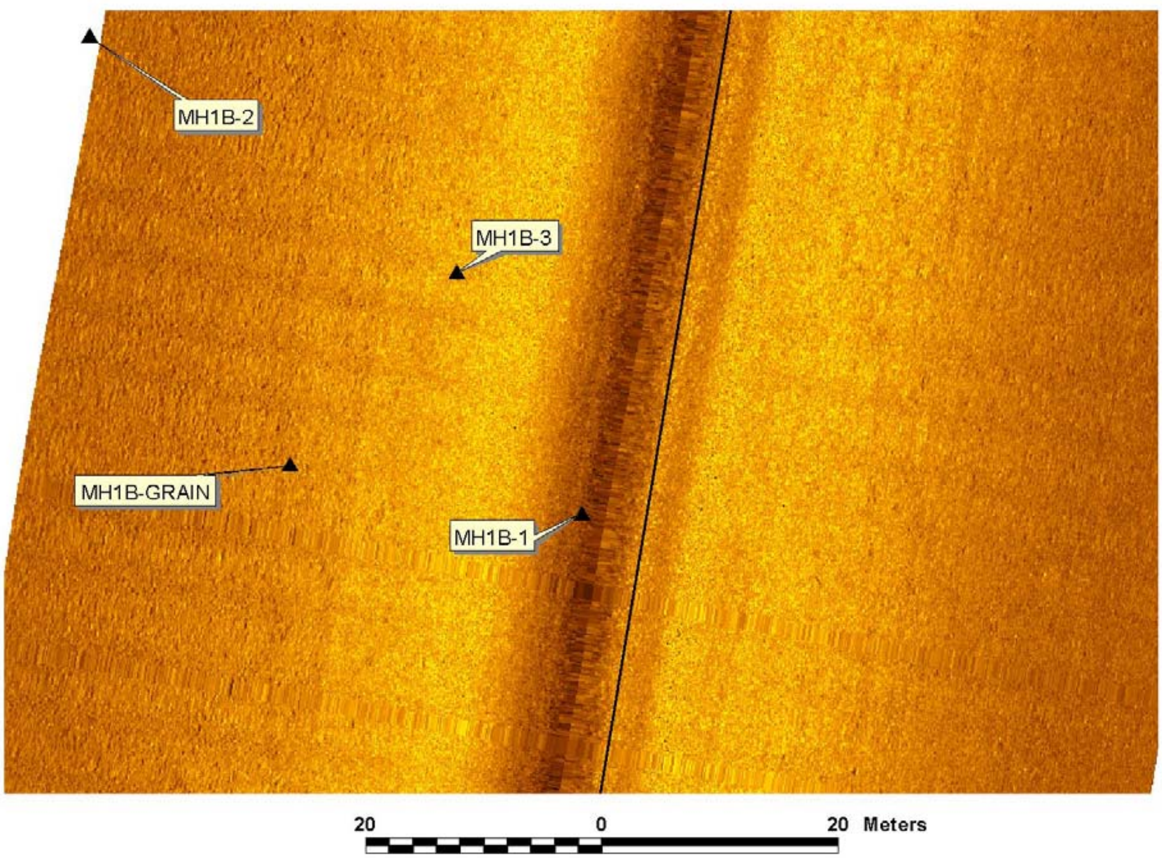

Figure 3.2.2.4-1a October 2002 grab sample locations in the vicinity of MH-1B

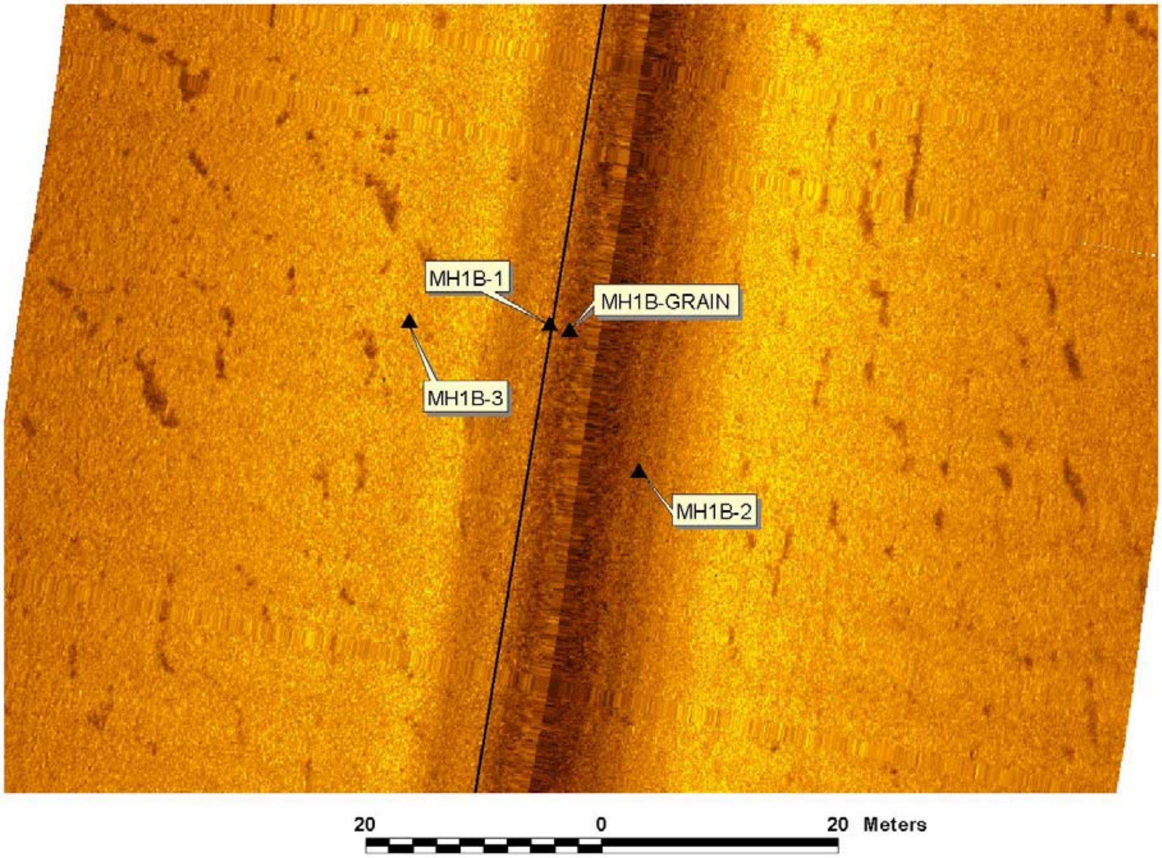

Figure 3.2.2.4 –1b November 2002 grab sample locations along Mud Hole Lane 1 at station B.

Mud Hole Control Lane 2 in the Vicinity of Station B

Bathymetric data shows that station MH-2B is located at the toe of a slope that rises to the northwest (Figure 3.2.1-1) in an area that appears to be characterized by flat sandy mud (see Appendix 3.2A Figure TS-6). Pre-trawl sonar data for station MH-2B shows faint background trawl gear impacts.

Lane 2 in Mud Hole was designated a control lane, however, some project-related gear impacts were observed in the western portions of the September 30th and November 20th sonar imagery in the vicinity of MH-2B. These gear impacts appear to have come within approximately 25-meters of the centerline of lane 2, i.e. just within the western edge of this control lane. As shown on Figure 3.2.2.4-2a (below) two of the grab samples collected in October may have been compromised by these trawl impacts (i.e. the MH2B grain size sample and the MH-2B benthic grab replicate 1). All November grab samples were collected from non-impacted areas closer to the center of this control lane (Figure 3.2.2.4-2b). Background door marks were still visible on the September and November side-scan imagery. Again trawl scours in November appeared broader and less distinct than in previous records and likely due to sediment transport from bottom currents associated with the November storm.

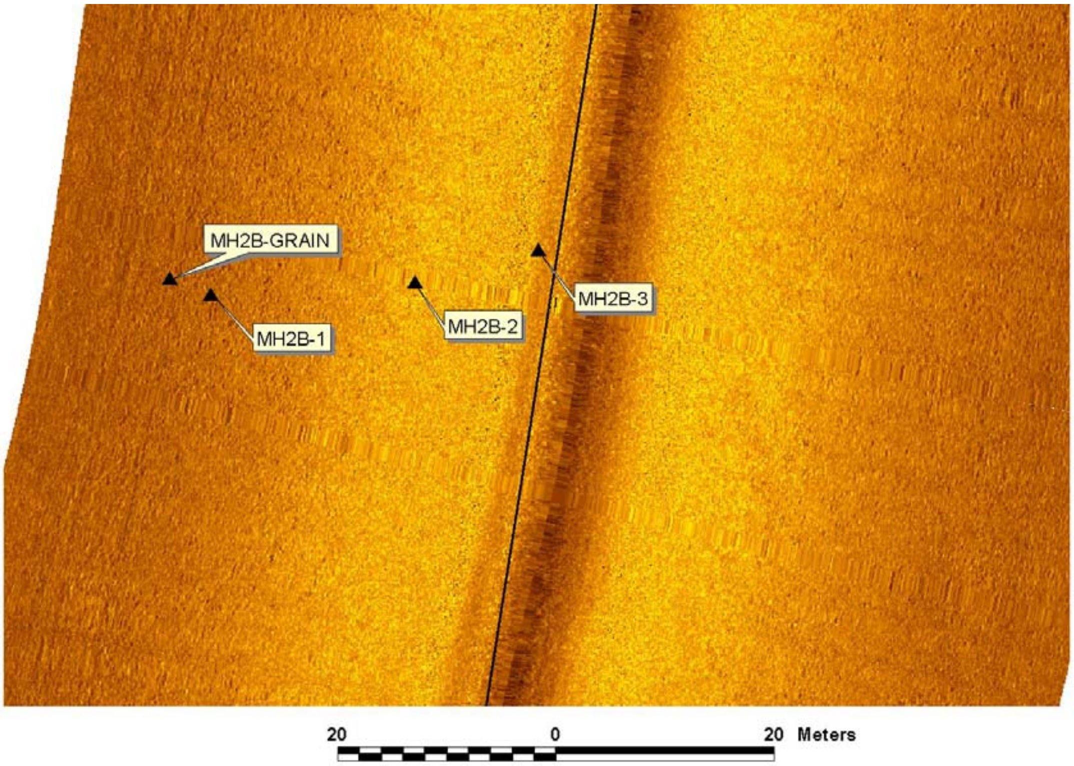

Figure 3.2.2.4-2a October 2002 grab sample locations along Mud Hole control lane 2 near station B

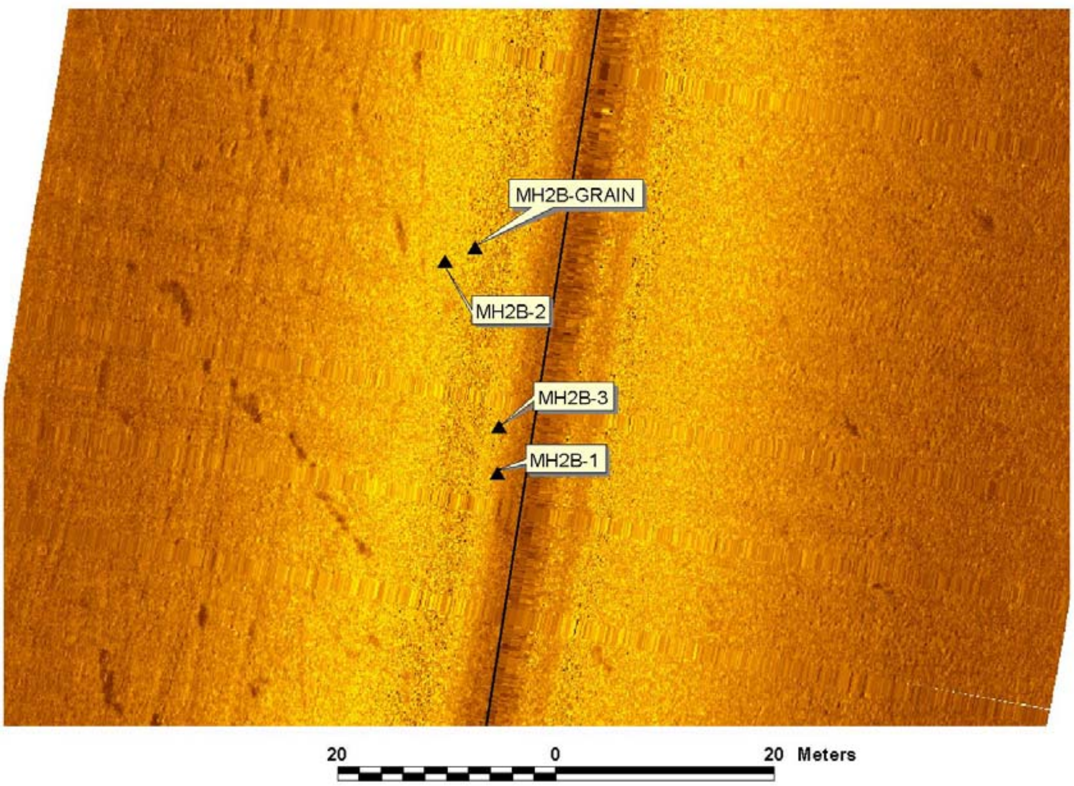

Figure 3.2.2.4-2b November 2002 grab sample locations along Mud Hole lane 2 near station B

Mud Hole Experimentally Trawled Lane 3 in the Vicinity of Station B

Mud Hole station MH-3B is located in a relatively flat portion of the survey area (see Figure 3.2.1-1). The substrate at this location appears to be sandy mud. Pre-trawl sonar data for MH-3B shows faint background gear impacts consistent with door marks (see Appendix 3.2-A Figure TS-7).

Project-related gear impacts on this experimentally trawled lane were clearly visible on the September 30th and November 20, 2002 sonar imagery near MH-3B. Background door marks observed during the pre-trawl survey remain visible on the September and November images. As noted for other stations, the November scours appear broader and less distinct than in previous records, likely due to bottom currents associated with the November storm. As shown on Figure 3.2.2.4 -3a and 3b (below), samples collected from MH-3B in October extended into the western portion of the trawl lane in an area directly impacted by trawl doors. November samples from MH-1B were clustered around the planned lane centerline where gear contact likely consisted of trawl chain and cookies.

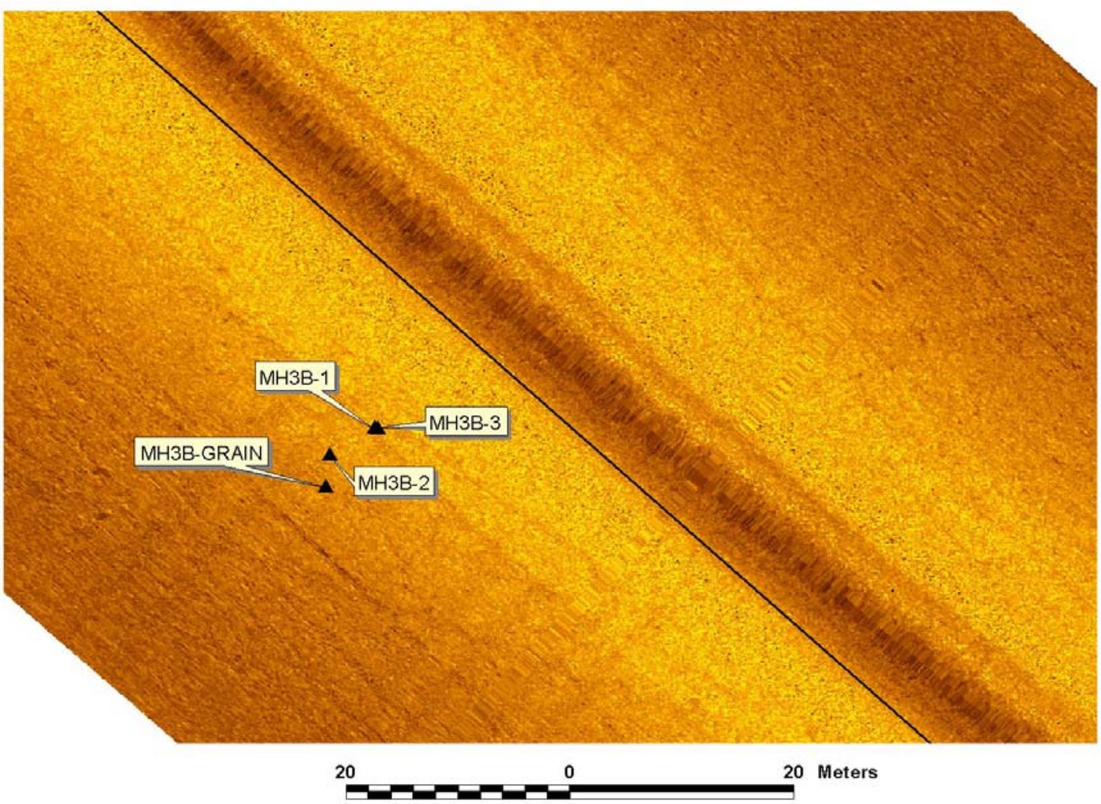

Figure 3.2.2.4-3a October 2002 grab sample locations along Mud Hole experimentally trawled lane 3 at station B

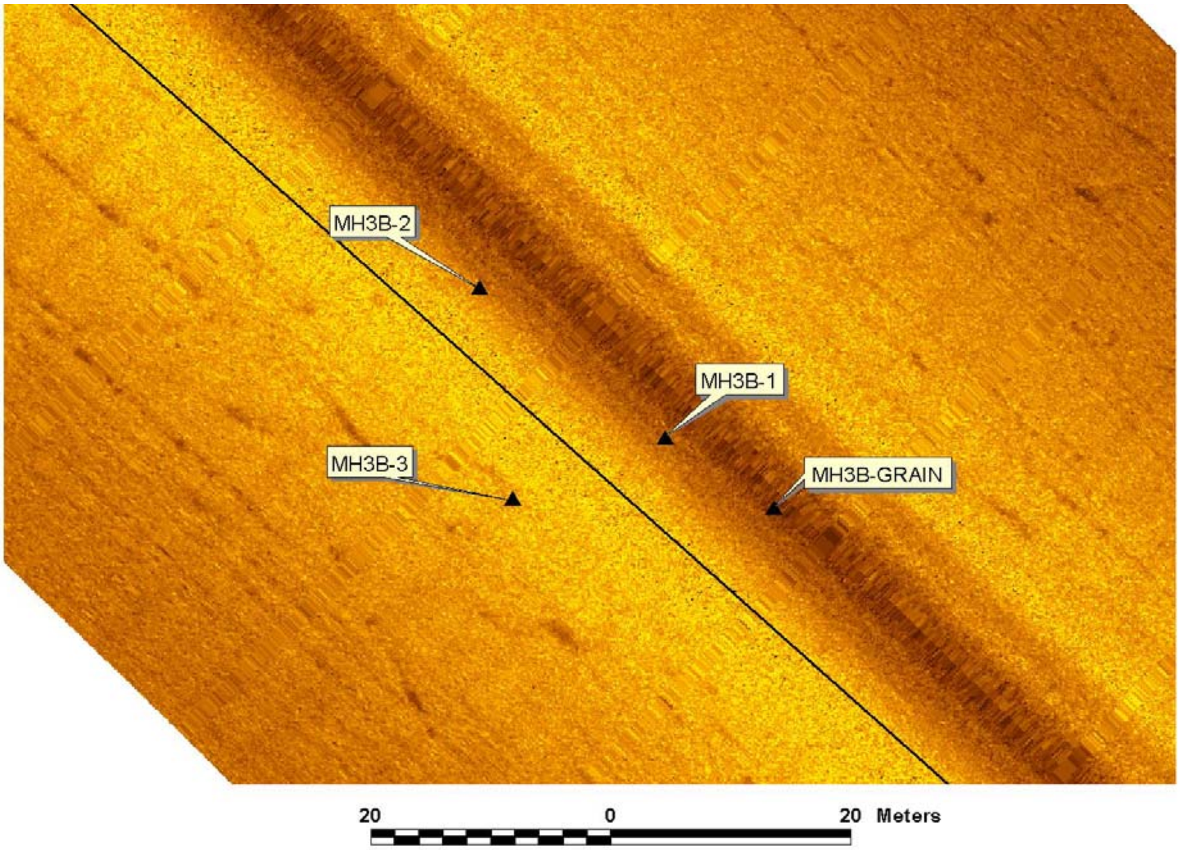

Figure 3.2.2.4-3b November 2002 grab sample locations along Mud Hole experimentally trawled lane 3 at station B

Mud Hole Control Lane 4 in the Vicinity of Station B

Grab sampling station MH-4B is located in a relatively flat portion of the study area (see Figure 3.2.1-1) and was the deepest station sampled in 2002. The substrate appears to be fine sandy mud (see Appendix 3.2-A Figure TS-8). Pre-trawl sonar data for Mud Hole control lane 4 near station B shows faint background trawl gear impacts oriented both parallel and roughly perpendicular to the lane. These background door marks were still visible on the September 30th and November 20, 2002 imagery. The scours observed in November appear broader and less distinct than in previous records, likely due to bottom currents associated with the November 2002 storm.

Control lane 4 in the vicinity of sampling station MH-4B was free of any project-related gear impacts following review of the September 30th and November 20, 2002 sonar imagery.

Little Tow Observations:

Little Tow Experimentally Trawled Lane 1 in the Vicinity of Station B

Pre-trawl sonar data for Little Tow lane 1 shows background otter trawl and scallop gear impacts along the entire length of the lane (see Appendix 3.2-A Figure TS-1, and Figure 3.2.2.1-2).

Station Little Tow lane 1 station B appears to be located in hummocky muddy sand with nearby sand waves. Project-related gear impacts were clearly visible on the September 30th and November 20, 2002 sonar imagery. Door scours observed in November appeared slightly wider and deeper than those observed in September, possibly due to the influence of the November storm. Door marks were observed within approximately 12-meters of the centerline of lane 1 near station B. Gear impact along the majority of the lane at this location was likely caused by the sweep of the net, chain and cookies.

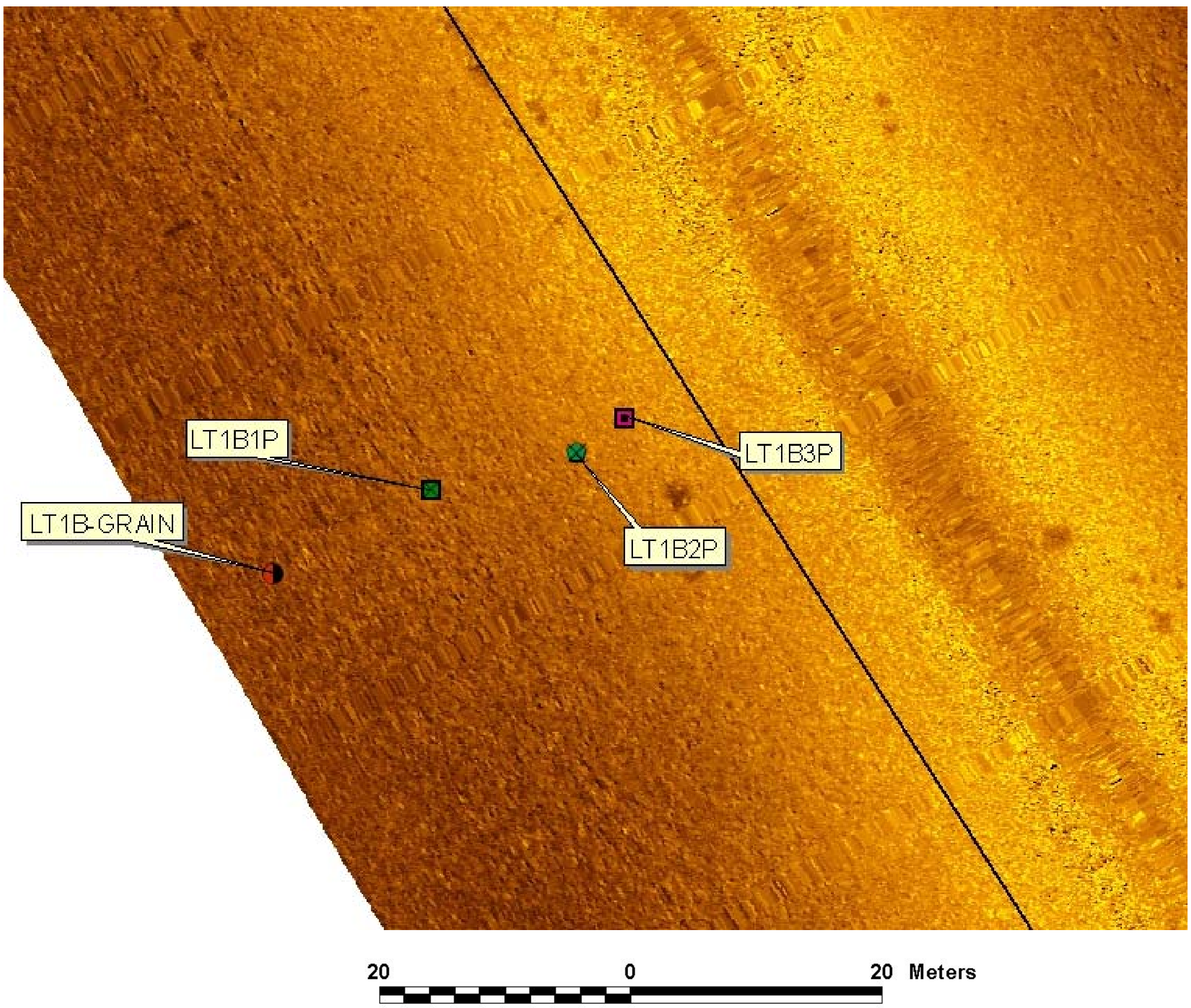

Figure 3.2.2.4 –4a October 2002 grab sample locations at Little Tow lane 1 station B

As shown on Figure 3.2.2.4 –4a (above) and Figure 3.2.2.4-4b (below) the majority of grab samples collected in September and November 2002 were located slightly to the western side of trawl lane 1 in an area shown to have been heavily impacted by project-related door impacts.

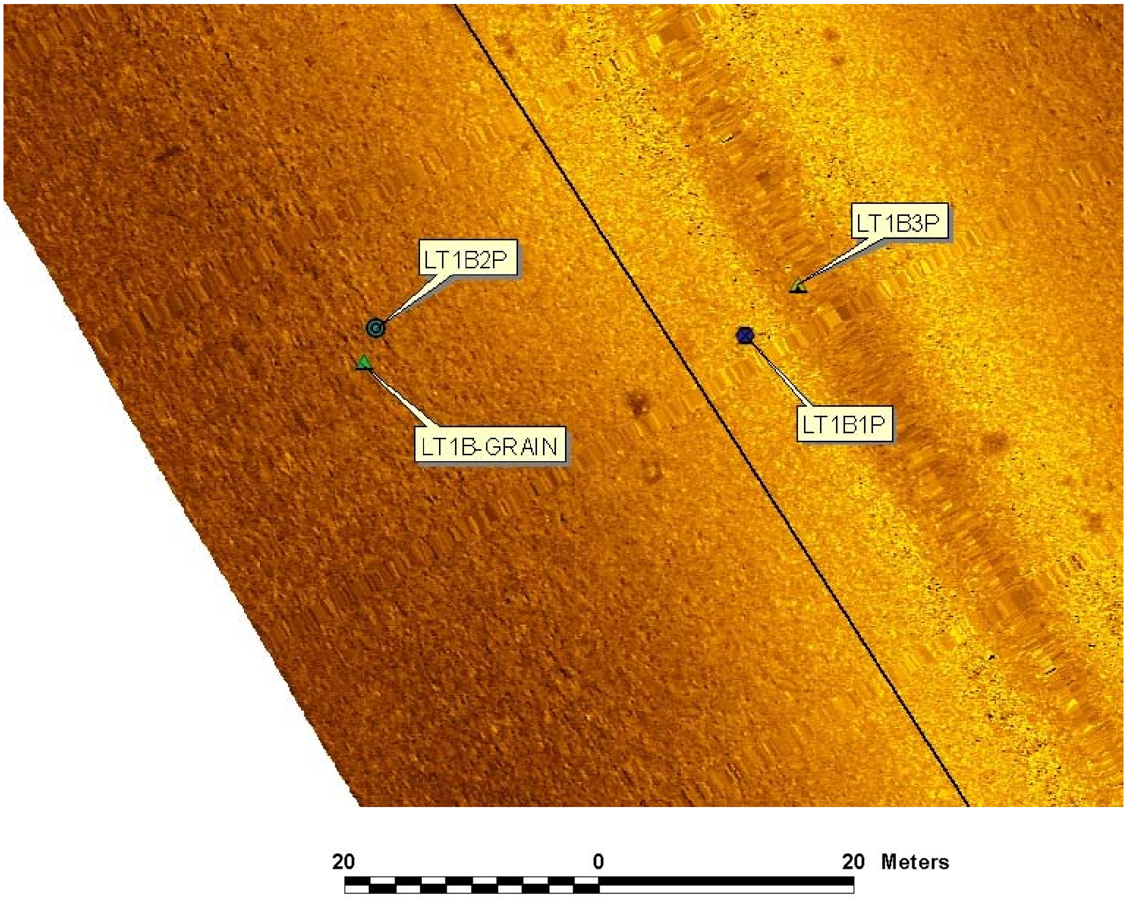

Figure 3.2.2.4 –4b November 2002 grab sample locations at Little Tow lane 1 station B

Little Tow Control Lane 2 in the Vicinity of Station B

Pre-trawl sonar data for the paired Little Tow reference lane 2 shows background otter trawl and scallop gear impacts along the entire length of the lane (see Appendix 3.2-A Figure TS-2). Little Tow lane 2 station B appears to be located in hummocky muddy sand within meters of a small patch of sand waves.

GIS analysis of grab sample locations and sonar data suggests that none of the samples collected from Little Tow control lane 2 near station B were impacted by any project-related fishing gear. Project-related gear impacts including door scours were visible to the southwest of Little Tow control lane 2 near station B on September 30th and November 20, 2002 sonar imagery, however, they were over 20 meters from the grab sampling stations.

Little Tow Experimentally Trawled Lane 3 in the Vicinity of Station A

Little Tow lane 3 station A is located in an area characterized by flat muddy sands widely interspersed with small to large cobbles and faint sand ripples (see Appendix 3.2-A, Figure TS-3). Bathymetric data shows that this area slopes gently down to the east (Figure 2.3.1-2). Pre-trawl sonar data for Little Tow lane 3 shows background scallop gear impacts along the entire length of the lane, but the density of gear impacts was slightly lower than that observed along the more northerly Little Tow lanes 1and 2. Note that fixed fishing gear prevented complete sonar coverage of lane 3 near station A in September (see Appendix 3.2-A Figure TS-3).

Project-related gear impacts were visible on this experimentally trawled lane on September 30th and November 20, 2002 sonar imagery. Door scours were most clearly visible on the northeastern portion of the lane. A few door scours appeared to cross directly over the planned survey centerline of lane 3 in the vicinity of station A. The majority of grab samples collected in September and November 2002 were clustered around the lane 3 centerline in an area heavily impacted by experimental trawl door impacts.

Little Tow Control Lane 4 in the Vicinity of Station A

Little Tow control lane 4 station A is located in an area characterized by flat muddy sands and faint sand ripples (see Appendix 3.2-A Figure TS-4). Bathymetric data shows that this area slopes gently down to the southeast (Figure 3.2.1-2). Pre-trawl sonar data for Little Tow lane 4 shows background scallop gear impacts along the entire length of the lane (see Figure 3.2.2.4-5).

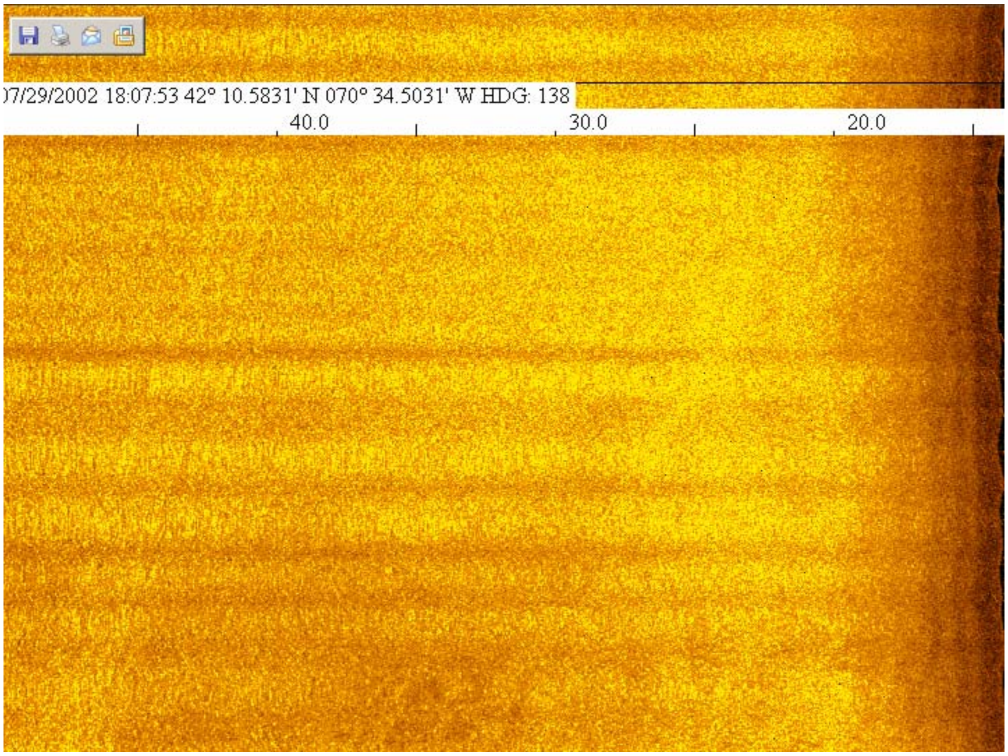

Figure 3.2.2.4-5 July 2002 pre-trawl background gear impacts at Little Tow control lane 4 near station A

Projected-related gear impacts were not observed on the September 30th and November 20, 2002 sonar imagery in the vicinity of control lane 4 near station A at Little Tow, and background impacts did not increase over the study period. However, the scallop gear marks observed in late July 2002 persisted through November 2002 (see Appendix 3.2-A Figure TS-4).

3.2.3 Physical Properties of Study Area Sediments

In our earlier 'acute' trawl impact study, July 12 through 14, 2001, the post-trawl sediments were of a lower median grain size at many of the sample stations, especially those with softer sediment compared to pre-trawl values. This trend occurred at both the Mud Hole and Little Tow sites, and in lanes that were experimentally trawled or not. The shift in modal grain size was from medium to fine sand. This suggested that the disturbance caused by the study's trawl gear, coupled with unquantified bottom currents, resulted in the resuspension and redistribution of surficial sediment and sediment transport beyond the trawled lanes since no major storm events occurred between the pre- and post-trawl sediment collection dates of July 12 and 14, 2001.

The 2002 sediment grain size results are detailed in the subsections that follow. Unlike the July 2001 study where sediment was sampled before and immediately after bottom trawling, the 2002 samples were collected over a number of months (late July, early October, and mid-November) and trawl impacts were chronic and not coupled with sampling events. The purpose of the sampling design was to identify potential changes in grain size of the surficial bottom sediment due to our experimental trawling or seasonal effects with the hope to further discern the mechanistic cause of the modal shifts observed during the 2001 acute trawl impact study.

The results of the 2002 sediment grain size analyses are in Tables 3.2.3-1 and 3.2.3-2, and Figures 3.2.3-1 through 3.2.3-4 are graphical representations of the data for Mud Hole and Little Tow, respectively. Figures in Appendix 3.2-B show the locations of sediment grab samples for grain size and benthic organisms (Section 3.4), and the corresponding side-scan sonar imagery. Coordinates for the sampling stations are in Appendix 3.4-A.

As mentioned earlier, a significant storm event occurred prior to the November 19, 2002 grab sampling. The storm began on November 16th and subsided by November 19th based on meteorological and oceanographic data recorded by the NOAA Boston Buoy 44013 and resulted in maximum wave heights of 5.5 meters (Figure 3.2.2.3-1).

3.2.3.1 Baseline conditions – July 31, 2002

Mud Hole

The dominant size fraction at Mud Hole in July was *medium sand* (median phi of 1.70 – 1.98) (Figure 3.2.3-1). Coarser fractions made up less than 3 percent of the samples. The fine sand fraction ranged from 8.9 to 22.9 percent and was highest at Station MH3B. The silt/clay fraction ranged from 7.3 to nearly 18 percent and was highest at the two southern Stations, MH3B and MH4B. The quartile deviation results provide an estimate of sediment homogeneity or the degree of sorting. Results ranged from 0.18 phi to 0.65 phi, suggesting sediments at Mud Hole are very well to moderately well sorted. Both quartile deviation and median phi values in July were highest at the two southern Stations, suggesting that this portion of the Mud Hole had a finer and more homogeneous substrate than the northern portion of the Site. *There was no detectable difference between the grain size distribution of the control versus the trawled lanes samples.*

Little Tow

Like Mud Hole the dominant size fraction at Little Tow in July was *medium sand* (median phi of 1.80 – 1.93) (Figure 3.2.3-2). The medium sand fraction was greatest at the two northern Stations, LT1B and LT2B. Coarser fractions made up less than 3 percent of the samples. The fine sand fraction was also similar to that at Mud Hole, and ranged from 9.0 to 19 percent. The fine sand fraction was substantially higher at southern Stations LT3B and LT4B. The silt/clay fraction in July was slightly greater and less variable than at Mud Hole, and ranged from 18.3 to 24.8 percent. *There was no detectable difference between the grain size distribution of the control versus the trawled lanes samples.*

Little Tow quartile deviation results ranged from 0.42 phi to 0.68 phi, suggesting sediments at Little Tow are well to moderately well sorted. Both quartile deviation and median phi values were lowest at the two northern Stations, suggesting that this portion of the Little Tow possesses a finer and more homogeneous substrate than the southern portion of the Site. This observation is supported by side-scan sonar imagery, which shows that the northern portion of Little Tow is less acoustically reflective than the southern portion, and by site bathymetry, which shows that the northern portion of the seabed at Little Tow is flatter and possesses fewer bathymetric irregularities than the southern portion.

3.2.3.2 Post-Trawl Site Conditions – October 9 and November 19, 2002

At Mud Hole and Little Tow there were no discernible differences between the grain size distribution for control versus trawled lane samples following chronic trawling efforts from the end of July to the middle of November.

Sediment particle size at Mud Hole was essentially unchanged from July 2002 to October 2002. One minor difference noted was slightly higher percentages of silt/clay at MH1B and MH2B in October than in July. Mud Hole sediment samples collected in November were similar to those collected in October. The dominant modal size was medium sand throughout the year. The silt/clay content ranged from 13.6 to 21.9 percent. Additionally, the fine sand fraction at Mud Hole stations decreased from July to October and from October to November.

Temporal changes were more pronounced at Little Tow where there was a shift in modal size from medium sand to fine sand between July and October (see Figure 3.2.3-2). The fine and very fine sand fractions significantly increased at Little Tow from July to October, and significantly decreased from October to November. The November modal grain size reverted to medium sand except at LT1B. Coarse sands at Little Tow significantly increased from July to October and from October to November. The silt/clay content of Little Tow sediments decreased from July 2002 to November 2002 in a roughly linear fashion, with July, October and November means of 19.9, 17.3, and 10.3 percent, respectively. A possible explanation for the pronounced changes at the more shallow stations of Little Tow is increased sediment mixing associated with seasonal or episodic differences in wave-induced bottom disturbances (see Figure 3.2.2.3-1 for a Time-Series record of wave heights in Mass Bay for 2002). As described previously, the November sampling event immediately followed a major northeasterly storm event. The average wave heights recorded for Mass. Bay during the 48 hours prior to the sampling events were 0.5 m (July), 0.8 m (October) and 1.9 m (November). Extensive seasonal changes in seabed morphology were documented by side-scan sonar data, and are described in Section 3.2.2.3.

3.2.3.3 Comparisons of July 2001 and July 2002 Grain Size Data

Sediments at both Mud Hole and Little Tow stations selected for sampling in 2002 were similar in grain size to those reported at the same sites in July 2001. The modal grain size was medium sand.

The median grain sizes at Mud Hole in July 2001 and July 2002 were 0.26 mm and 0.29 mm, respectively. The median grain sizes at Little Tow in 2001 and 2002 were 0.26 mm and 0.27 mm, respectively. The medium sand content tended to be higher and the percent coarse sand lower in July 2002 than in July 2001. There was very little material in the size of coarse sand or greater at Mud Hole or Little Tow (<3%). Sediments at Little Tow had a slightly higher silt/clay content in 2002. The quartile deviation values, which provide an estimate of sorting, suggest well to very well sorted sediments at both areas as was found in July 2001 (0.18 to 0.68 phi).

3.2.3.4 Summary Sediment Composition

Sediment composition was fairly consistent from year to year in the study. Site selection for 2002 samples was based on similarity of sediment type documented in 2001. All had a major modal size in the range of fine to medium sand, typically 50 to 80 percent, with a smaller mode of silt/clay (5.5 – 24.8%). Sediments throughout the lanes varied somewhat, especially at Little Tow. Video transects used in this study have demonstrated the variability of sediments over short distances (meters) with mounds and depressions. Raised areas are coarser since they are exposed to current flow and the depressions accumulate finer sediments.

Variations in sediment composition were reported for both trawled and non-trawled lanes which suggests that the differences in these data are not due to the effects of bottom trawl gear. For example, in November 2002, trawled station LT1B had more fine sand and silt/clay than the adjacent control station LT2B. Since these sites were very similar in sediment composition in October, the most probable explanation is local variability and enhanced heterogeneity related to the major November storm event.

The modal shift from medium to fine sand that was observed at Mud Hole and Little Tow trawled and control lanes during the 2001 ‘acute’ trawl impact study was also observed in 2002, but the shift occurred only at Little Tow. The shift was most pronounced in the October 2002 data set, but persisted through November. Conversely, the fine sand fraction at Mud Hole stations decreased from July to October and from October to November. Based on these contrasting trends, it is unclear whether either of these shifts in particle sizes was related to project trawling. It seems more likely that the shifts observed are related to natural currents, both tidal and weather-driven, and to variations of seabed topography.

3.0 CHRONIC TRAWL STUDY RESULTS

3.1 Water Column Characteristics

Representative plots of water quality profiles and CTD cast logs for each of the three cruises in August, October and November 2002 are provided in Appendix 3.1-A.

CTD casts at Mud Hole were taken from 9:38 to 11:22 on August 1, 2002, with the exception of the cast at MH-3A (17:19). Casts at Little Tow were taken between 14:26 and 18:38 on August 1, 2002. Surface water temperatures at Mud Hole and Little Tow were around 20 degrees C. A steep thermocline was present between about 10 and 60 ft, with bottom temperatures of approximately 7 degrees C. Salinity profiles were fairly uniform at both sites, with surface (0 to 30 ft) salinities of approximately 31 to 31.5 ppt (parts per thousand) and slightly higher salinities in deeper water of about 32 ppt. Turbidity was non-detectable (<2 FTU) throughout the majority of the water column. Turbidity at the mid-thermocline and within 10 ft of the bottom was slightly greater than the 2 FTU quantification limit. Dissolved oxygen (DO) measurements ranged from approximately 5 to 9 mg/l, and appeared to be influenced by minor variations in salinity.

On October 10, 2002, CTD casts at Mud Hole were taken between 9:27 and 11:33, and at the Little Tow site between 11:57 and 14:38. The thermocline recorded on the October 10th cruise was less pronounced than during the early August monitoring effort. The surface temperature was approximately 15.5 degrees C, and the bottom temperature was approximately 10 degrees C. Salinity ranged from approximately 31 to 33 ppt, and was lowest near the surface. Turbidity remained non-detectable (<2 FTU) throughout the majority of the water column with slightly higher (2 to 4 FTU) measurements at the mid-thermocline and within 10 ft of the sediment surface. DO levels ranged from approximately 3 mg/l near the water surface to approximately 2 mg/l near the bottom. There were no obvious differences between profile parameters measured at Mud Hole and Little Tow or between trawled and control lanes.

On the November 12, 2002, CTD casts at Mud Hole were taken between 8:59 and 11:30 and at Little Tow between 11:54 and 14:24. The water column at both sites was nearly isothermal during the November 12th cruise with water column temperatures between 10 and 11 degrees C. The salinity profiles reflect this well-mixed condition with water column salinity ranging from approximately 32.0 to 32.5 ppt. Turbidity remained non-detectable (<2 FTU) throughout the majority of the water column with slightly higher (2 to 20 FTU) measurements within 10 ft of the sediment surface. DO concentrations near the surface were approximately 3 to 5 mg/l, and bottom concentrations were approximately 2.5 mg/l. There were no obvious differences between profile parameters measured at Little Tow and Mud Hole or between trawled and control lanes.

Seasonal trends at the study sites included:

- The breakdown of a steep thermocline present at the beginning of August to a nearly isothermal/well mixed water column by late fall.

- Water column salinities ranging from 31 to 33 ppt over the study period, and slightly lower salinities near the surface during the summer.

- Dissolved oxygen levels generally slightly higher in the surface waters compared to the bottom water and highest in the summer.

- Low turbidity throughout the water column during the study period with some slightly higher readings within 10 ft of the bottom and mid-thermocline.

3.3 Video Sled Results

Visual observations and side-scan data (Section 3.2.2) indicate that the seafloors at Mud Hole and Little Tow represent quite different habitats. These observations were originally made in 2001 and were again confirmed during the 2002 study. The seafloor at Mud Hole consists of fine-grained sediments that form hard, flat mud in the northern region (Plates 3.3-1 and 3.3-2) and gradually grade into hummocky flocculent mud in the southern region (Plates 3.3-3, 3.3-4, 3.3-5, and 3.3-6). Much of the surface of the seafloor in Mud Hole appears to be structured by biological forces, as evidence are numerous microtopographic features such as tubes, feeding depressions, mounds, and tracks and trails. In contrast, much of the seafloor at Little Tow appears to be structured by physical forces. At Little Tow the seafloor is muddy only in the northern region (Plates 3.3-7 and 3.3-8) and grades into rippled sand and well-defined sand waves in the southern region (Plates 3.3-9, 3.3-10, 3.3-11 and 3.3-12). The sandier regions evidence much less infaunally produced microtopography, such as tubes, feeding depressions and mounds. Additionally, shell material tends to be more abundant in Little Tow. Within-region habitat variability (patchiness) also appears to be much more pronounced in Little Tow.

Several interesting phenomena were observed in the video. Side-scan data had indicated large-scale changes in the sea floor of Little Tow following a strong northeastern storm in middle November. Basically, the sea floor in the entire southern region of Little Tow was changed into large expanses of very uniform sand ripples. These ripples were very visible on the video (Plate 3.3-13). Additionally, while trawl marks were very evident on the video footage collected in 2001, this was not the case in 2002. Very few instances of seafloor disturbance by fishing gear was noted in 2002. This may well have been an artifact of the exceptionally poor visibility that was encountered in 2002. In 2001, trawl marks were the most evident in the ROV footage which approached the lanes perpendicular to the direction of tow. While the 2002 video-sled drifts also approached the lanes perpendicular to the direction of tow, the camera needed to be kept right on the bottom, which substantially hampered the depth of field and shadowing necessary to discern seafloor structure.

3.3.1 General Faunal Patterns

Seven identifiable species categories of fish were observed on the video-sled footage. Some representative species are shown on Plate 3.3-14. A total of 432 fish were seen, 278 in Mud Hole and 154 in Little Tow (Table 3.3-1- raw video sled counts). The most abundant of these were red hake (185 individuals), flounder (121 individuals), silver hake (33 individuals), sculpin (32 individuals), and ocean pout (24 individuals). Additionally, two skates, one sea robin, and 34 unidentified fish were also seen. Some differences in the composition of the fish fauna were noted between the two study areas. Red hake totally dominated the fish in Mud Hole, accounting for 50% of the fish seen, but only accounted for 29.8% of the fish seen in Little Tow. Flounder were present in roughly equal proportions, accounting for 27.7% and 28.5% of the fish seen at Mud Hole and Little Tow, respectively. Sculpin and silver hake accounted for a greater portion of the fish seen in Little Tow (14.9% and 10.4%, respectively) than in Mud Hole (3.3% and 6.1%, respectively).

Twenty identifiable invertebrate species were seen on the video-sled footage (Table 3.3-1- raw video sled counts). A total of 5,941 invertebrates were seen, 2,827 in Mud Hole and 3,114 in Little Tow. White sea stars (consisting of *Asterias vulgaris* and *Leptasterrias tenera*) were by far the most abundant invertebrates seen. They accounted for 75.8% and 58.5% of the invertebrates seen in Mud Hole and Little Tow, respectively. Shrimp were the second most abundant invertebrates encountered, accounting for 33.3% of the invertebrates seen in Little Tow and 23.8% of the invertebrates seen in Mud Hole. Other less numerous invertebrates seen included rock crabs (173 individuals) and scallops (52 individuals) in both areas, and sand dollars (61 individuals) and sponges (47 individuals) only in Little Tow.

Standardized numbers of fish and invertebrates per minute are shown in Table 3.3-2 and Figures 3.3-1 and 3.3-2. The abundance of fish varied both spatially and seasonally. Fish were generally most abundant in November, and tended to be more abundant in Mud Hole than in Little Tow. The seasonal differences in fish abundance were most pronounced in Mud Hole, where fish averaged from 0.47 to 1.03 individuals per minute in July and October and increased to 2.75 to 3.01 individuals per minute in November (Figure 3.3-1). This seasonal increase in number of fish was consistent throughout all six areas of Mud Hole (Figure 3.3-3a). Seasonal differences in fish abundance were substantially less pronounced in Little Tow, where fish averaged from 0.10 to 0.74 individuals per minute in July and October and increased to 1.16 to 1.51 individuals per minute in November (Figure 3.3-1). In addition, the seasonal increase in number of fish was spatially inconsistent in Little Tow, where it was observed in only three of the six sites (Figure 3.3-3b). Fish were also much more patchily distributed in Little Tow than in Mud Hole.

In both areas, most of the increase in the number of fish seen in November was attributable to the red hake *Urophycis chuss* (Figure 3.3-4). This species was only seen in appreciable numbers in November. However, it is possible that some of the unidentified juvenile fish seen in July and October may have been juvenile red hake that were not readily identifiable on the video. The second most abundant fish were flounder and they were present in roughly equal numbers during all three surveys. Flounder were also slightly more abundant in Mud Hole than in Little Tow. Silver hake were an important component of the fish fauna in both areas, were seen only sporadically in October, and rarely in November. The other fish consisted mainly of sculpin in July, and unidentified juvenile fish in October and November.

Invertebrates exhibited different seasonal and spatial distribution patterns. Invertebrates were most abundant in Mud Hole in July and most abundant in Little Tow in October (Table 3.3-2 and Figure 3.3-2). However, this overall seasonal pattern was not found throughout the study areas. The northern region of Mud Hole generally supported far fewer invertebrates than the southern region (Figure 3.3-5a). Additionally, the number of invertebrates did not vary seasonally in the northern region, whereas they were substantially more abundant in the southern region in July. No consistent spatial or seasonal patterns in invertebrate density were observed in Little Tow. However, invertebrates were more abundant in October at four of the six areas surveyed (Figure 3.3-5b).

Two species categories, white sea star and shrimp, accounted for most of the invertebrates seen (Figure 3.3-6). Of the two, sea stars were the most ubiquitous. They were seen at all locations and appeared in relatively equal numbers during all three sampling dates. The lower number of invertebrates in the northern region of Mud Hole appears to be a direct reflection of fewer sea stars in this hard, flat mud region. Varying numbers of shrimp appear to be responsible for the observed seasonal shifts in the abundance of invertebrates. In Mud Hole, shrimp were a dominant component of the invertebrate fauna only in July and only in the southern region. In Little Tow, shrimp were abundant in both July and October, with the highest abundances observed in October. Rock crabs (*Cancer* spp.) were present in all areas during all seasons, but were never found in very high numbers. Sand dollars were only observed in the sand wave region in the southern portion of Little Tow at 4B in October and at 3B and 4B in November. An unidentified encrusting sponge was a dominant inhabitant of patches of cobbles and boulders found at 3A in Little Tow in October and November.

Trawled verses Control Areas

Overall, the abundance of megafauna did not appear to be affected by the chronic experimental trawling (Tables 3.3-3 and 3.3-4). No consistent differences were found between the trawled and control areas. It was also interesting to notice that trawling did not appear to alter the overall faunal composition. Additionally, similar seasonal distribution trends and shifts in faunal dominants were observed in both trawled and control areas.

In Mud Hole, the fish fauna was dominated by flounder and silver hake in July and October and by red hake and flounder in November (Figure 3.3-7a). Several small differences between trawled and control areas were noted in Mud Hole. Flounder were slightly less abundant in the experimental areas in July and October, but not in November. In contrast, in October and November silver hake were only seen in the trawled areas. However, when looked at in greater detail these differences were not consistently found in all areas and may be a reflection of faunal patchiness (Figure 3.3-8). In Little Tow, the fish fauna was dominated by flounder and silver hake in July and flounder and red hake in November, and was very depauperate in October (Figure 3.3-7b). No consistent differences between trawled and control areas were noted in Little Tow. Flounder were more abundant in the trawled areas in July and November, and red hake were more abundant in the control areas in November. Again, these differences appear to reflect a high degree of faunal patchiness (Figure 3.3-8). The invertebrate fauna also does not reflect any consistent differences between the trawled and control areas (Figure 3.3-9a and Figure 3.3-9b). The only major difference that was noted was a higher number of shrimp in the control areas in Little Tow in October, than in the trawl areas. This increase was noted in all three of the control areas and thus does not appear to reflect faunal patchiness (Figure 3.3-6).

3.3.2 Comparison with 2001 results

Very few valid comparisons can be made between the 2001 and 2002 video data. The experimental design and the survey techniques differed substantially between the studies. The 2001 study conducted intense experimental trawling at one point in time and was oriented toward assess the immediate effect of trawling. In contrast, the 2002 study was conducted over a period of time to assess the effects of chronic, lower intensity trawling. The 2001 study mainly used data collected from footage obtained from a video-sled operated in a towed mode and from a remotely operated vehicle (ROV). The data for the 2002 study consisted entirely of data collected footage obtained from the video-sled operated in a drift mode. The 2002 data is most comparable to the ROV data from 2001. Both techniques utilized a cross lane survey design at specific points along the experimental and control lanes. In contrast the towed video-sled was run along the entire length of the lanes. Additionally, the towed video-sled moved relatively fast (1 to 2 knots) along the sea floor and hence would "image" a greater proportion of fish that show avoidance behavior such as silver hake and flounder. In contrast, the ROV and drift video-sled move along the bottom much more slowly and would tend to "image" more sedentary fish, such as ocean pout and red hake.

The most direct comparison that can be made between the 2001 and 2002 data is between the 2001 pre-trawl ROV data and the July 2002 data (Table 3.3-5). In 2001, twice as many fish were seen in Mud Hole (0.35±0.30 and 0.46±0.12 individuals per minute) than in Little Tow (0.25±0.13 and 0.27±0.21 individuals per minute). In contrast, fish were present in almost equal densities in the two areas in July 2002, with fish ranging from 0.47±0.45 to 0.68±0.26 individuals per minute in Mud Hole and from 0.74±0.36 to 0.72±0.19 individuals per minute in Little Tow. Additionally, the faunal composition of fish was slightly different among the years. In 2001, red hake were an important part of the fauna in Mud Hole, whereas they were not present in July 2002. In contrast, flounder were a relatively small proportion of the fish seen in Mud Hole in 2001, and a major proportion of the fish seen in July 2002. At Little Tow, sculpin and ocean pout were both major components of the fish seen in 2001, while only sculpin were an appreciable proportion of the fish seen in Little Tow in July 2002. Part of these differences may be partially related to differences between the survey techniques. The ROV probably moved across the sea floor more slowly than the drift video-sled and may also have created more of a disturbance. This would tend to scare fish with strong avoidance behavior, and thus under represent them. However, visibility was also much lower in 2002 than in 2001 and the video-sled would have needed to be very close to a fish to successfully "image" it.

Overall invertebrate densities were comparable between the two years (Table 3.3-5). Sea stars were the dominant invertebrates seen during both years. However, the high abundance of shrimp noted in 2002 was not evident in 2001. Again, this discrepancy may be related to differences between the survey techniques. Due to the very poor visibility encountered in 2002, the video-sled was run very close to the sea floor making it possible to "image" organisms that might not have been seen if the camera was slightly further away (as may have been the case in 2001). Several similarities between the two years were noted. In both years, sea stars were less abundant in the northern part of Mud Hole (Stations 1B and 2B) than in the southern part. Additionally, sand dollars were also important, yet patchily distributed inhabitants of the sand waves found in the southern region of Little Tow during both years (see Plates 3.3-14, 3.3-15 and 3.3-16).

3.4 Benthic Results and Discussion

Benthic infaunal grab samples from Mud Hole and Little Tow produced 58,600 individuals of 238 species. Raw data for station replicates and sampling coordinates are provided in Appendix 3.4-A. The fauna was diverse and abundant, typical of that seen in other areas in Massachusetts Bay. The sediments influenced species composition and distribution. Some species were more abundant in the fine sands with high levels of silt/clay while others were more common in the medium sand sediments with lower levels of silt/clay. Unlike samples from our 2001 trawl study, where the dominant species in 49 of the 67 grab samples analyzed was the small spionid polychaete, *Prionospio steenstrupi,* there were several other species that were more abundant in the 2002 grabs particularly at Little Tow. Species dominance, based on total counts for a species from three replicate samples at each station (Tables 3.4-1 and 3.4-2), was shared among five species (*Prionospio stennstrupi*, *Spio limicola*, *Nucula delphinodonta*, *Phoronis architecta*, and *Dipolydora socialis*). Figures 3.4-1 through 3.4-4 are graphs of average individuals per grab of key species in the paired control and trawled lanes for Mud Hole and Little Tow over the study period. There was an apparent shift in dominance at many sites from *Prionospio steenstrupi* in 2001, to *Spio limicola* in 2002*.* *Prionospio* remained an important component of the fauna where *Spio* dominated, and was typically the second most abundant species except at some sites in Little Tow.

3.4.1 Mud Hole Baseline Results (July 2002 pre-chronic trawling)

Benthic grab samples taken in July from the trawled lanes at Mud Hole averaged 836 individuals of 60 species. These parameters were not significantly different from the control lanes (63 species, 1043 individuals).

At both trawled stations (MH1B, MH3B) S*pio limicola* was the dominant species. *Prionospio* and *Nucula delphinodonta* were the next most abundant species at MH1B. *Dipolydora socialis* and *Prionospio* were the second and third most numerous species at MH3B. The small bivalve, *Nucula* was present in good numbers at MH1B (179), but did not feature on the dominant species list at MH3B (38 individuals).

Spio limicola was also the dominant organism (30.2 – 34%) at the control lane stations prior to chronic trawling, with *Prionopsio* being the next most abundant organism (13.9 – 18.9%), followed by *Dipolydora socialis* (6.7 – 5.8). The bivalve *Thyasira* was common at both control lane stations. Again, *Nucula delphinodonta* was present in good numbers, 207 found in the north (MH2B), but not at the southern site (MH4B). Most of the remaining dominants were polychaetes, common to both control lane stations.

There was considerable overlap in the remaining species listed as dominants in both the trawl lanes and control lanes. Both northern lanes (MH1B-trawled and MH2B-control) where *Nucula* was abundant had 10 to 20% more medium sand and less fine sand than the southern Mud Hole stations.

3.4.2 Mud Hole Post-Trawl Results (October 9 and November 19, 2002)

The first set of post-trawl samples taken from the Mud Hole trawled lanes in *early October 2002,* had an average of 61 species and 910 individuals. *Spio limicola* was the dominant species at both stations (MH1B and MH3B) with *Prionospio* the next most abundant organism. The remaining dominant species were predominantly polychaetes such as *Dipolydora socialis, Mediomastus californiensis, Maldane sarsi, Tharyx acutus* and *Anobothrus gracilis*. The small bivalve *Nucula delphinodonta* was among the dominants at the northern station (MH1B) both before and after trawling. At the southern station (MH3B) this species was present but not abundant for each of the sampling events. All of the other species listed as dominants in the pre-trawl survey were common or abundant in the post-trawl data. The second set of post-trawl samples taken in November 2002 from the experimentally trawled lanes, averaged 67 species and 890 individuals. They were not significantly different in number of species and individuals from either the July pre-trawl or October post-trawl sampling results.

In the control lanes, the first post-trawl samples (October) averaged 61 species and 874 individuals. Similar to the trawled lanes, S*pio limicola* was dominant in all cases except at MH4B where densities of *Spio* and *Prionospio* were almost the same (685 and 654 individuals, respectively). Other than the small molluscs, *Nucula delphinodonta, Thyasira gouldii*, and *Phoronis architecta*, the remaining species listed among the most numerous were all polychaetes. These included *Mediomastus californiensis, Tharyx acutus, Aricidea catherinae, Dipolydora socialis and Anobothrus gracilis.* The composition of the remaining dominant species was not significantly different from that found at the trawled stations. The November post-trawl samples had 64 species and 884 individuals. There were no major changes in faunal composition.

3.4.3 Little Tow Baseline Results (July 2002 pre-chronic trawling)

Species richness and densities at the benthic stations in Little Tow were similar to those found at Mud Hole.

Pre-trawl samples at the trawled lanes (LT1B and LT3A) averaged 797 individuals of 63 species. *Prionospio* was the dominant species at LT1B, but *Spio* was more abundant at LT3A. Other components of the fauna were similar. Additional polychaetes included *Tharyx acutus, Anobothrus gracilis* and *Mediomastus californiensis*. Non- polychaete species that were common were the bivalves, *Thyasira gouldii* and *Nucula delphinodonta.* The isopod, *Ptilanthura tenuis* was among the dominants at LT1B, but was present in much reduced numbers at LT3A. Many of the dominant species were the same as those found at Mud Hole.

The pre-trawl samples at the control lane stations (LT2B and LT4A) had mean densities of 644 organisms per grab and 56 species. *Dipolydora socialis* was the most abundant species at LT2B and *Prionospio* was the most common species at LT4A. Six other dominant species were common to both control lane stations. There were significant numbers of the tube dwelling amphipod *Unciola inermis* in two samples at LT2B but this species was barely represented at Station LT4A (4 individuals).

3.4.4 Little Tow Post-Trawl Results (October 9 and November 19, 2002)

Average densities in the first post-trawl samples taken in early October at trawled lane stations (LT1B and LT3A) were 875 individuals, and species richness was 62 organisms per grab. This was not significantly different from the pre-trawl results. *Prionospio* was dominant in both trawled lanes in the first post-trawl sampling. In the second post-trawl sampling, in November, *Prionospio* remained dominant at LT1B, but at LT3A both *Spio limicola* and *Anobothrus gracilis* were more abundant than *Prionospio*. The remaining components of the fauna were quite similar before and after trawling.

The control lane stations (LT2B and LT4A) at Little Tow averaged 602 individuals of 54 species in October. *Dipolydorus* was no longer the most abundant species. The most common species was *Nucula delphinodonta* followed by *Anobothrus gracilis*. There were only 19 individuals of *Prionospio*, which had been the dominant organism in the pre-trawl samples. There were significant numbers of a Foraminiferan (Sarcodina A) in both post-trawl sampling events. The most numerous species at LT2B in the November survey was *Phoronis architecta*. The amphipod *Unciola inermis*, common in pre-trawl samples (56 individuals), was represented by only two individuals in the post-trawl surveys. This was probably due to a slight change in grain size since *Unciola* prefers sandier sediments. At LT4A, *Nucula delphinodonta* was numerically dominant in both post-trawl samplings. *Prionospio* was ranked among the middle of the other dominants, which included *Spio limicola*, *Tharyx acutus*, *Owenia fusiformis*, and *Phoronis architecta*, all of which were among the dominant species in pre-trawl samples.

3.4.5 Community Analyses

Faunal data was subjected to cluster analysis and ordination methods including principal components analysis using the software package BioDiversity Professional, Version 2. The data was subjected to a square root transformation to reduce the influence of abundant species. No species were present in extremely high abundances (1,000's per grab) and hence the more severe log transformation was not deemed necessary. Comparisons between square root and log transformations in test runs showed no significant differences in the way samples clustered. The Bray-Curtis similarity coefficient was calculated between sample pairs and the resultant data was subjected to group average clustering. Analyses were performed on combined replicate data (results from 3 replicates summed) and on individual replicates. A single replicate sample (LT2B-P1-3) was dropped from analyses because the sample was not preserved correctly and animals had disintegrated. For comparisons between years 2001 and 2002, replicate data from the same sites in each year was averaged since there were varying numbers of replicates (1 to 3) collected in 2001. Dendograms illustrating differences based on sites, seasons, and years (2001 verses 2002) are shown in Figures 3.4-5 and 3.4-6. Clusters of individual replicates and the results of principal components analysis are shown in (Figures 3.4-7 through 3.4-14).

Figure 3.4-5 shows the results of clustering the combined replicates from all of the 2002 samples. The samples clearly separated by area, with the samples from Mud Hole grouping into the first two clusters and the samples from Little Tow grouping into the remaining clusters. Additionally, samples within each of the areas further separated. In Mud Hole further separations were based on location (north verses south) and sampling date. In contrast, samples from Little Tow separated by one site (2B) being different from the three remaining sites and then mainly by season. *In both Mud Hole and Little Tow, samples from control and trawled lanes clustered together indicating that trawling did not have a measurable impact on benthic community structure.*

Similarity was relatively high (>75%) among the samples from Mud Hole. The greatest separation was between the northern (1B and 2B) and southern lanes (3B and 4B). Within each location, samples further clustered by sampling date, with the July and November samples being more cohesive than the October samples. This pattern of strong geographic differences between the northern and southern lanes was also reflected in the analysis of the individual replicates (Figure 3.4-7). Slight separations based on sampling date were also noted. Samples from trawled lanes did not separate from control lanes in any of the analyses. Ordination analysis using principal components confirmed the results of the cluster analysis (Figure 3.4-8). *Samples clearly separated based on north/south location and sampling date, but not on trawled verses control designations.*

Similarities among samples from Little Tow were more variable than at Mud Hole. The samples from Little Tow station 2B were the most unique, forming outliers to the main clusters (Figure 3.4-5). The other three sites at Little Tow tended to cluster together, with the pre-trawl (July) samples from LT1B, LT3A and LT4A clustered together and separate from post-trawl samples. In the post-trawl groups, station identity was a stronger factor than experimental impact. Samples from each station were grouped together based on location rather than trawl impact. The distinction of samples from Little Tow 2B, a control lane, was due to the fact that *Dipolydora* was the dominant species in pre-trawl samples and *Nucula* and *Phoronis* were the most numerous species in October and November, respectively. In contrast, top dominants at the other stations were usually *Prionospio* and *Spio*. The trends of the uniqueness of station 2B and the seasonal influence were also observed in the clustering of the individual replicates (Figure 3.4-9). Ordination analysis (Figure 3.4-10) supports the cluster analyses by showing Station 2B as the most distinctive site, and the fall samples separating from the July samples. *Again, as was found in Mud Hole, no evidence of trawl impact was observed, with samples separating by season rather than trawled verses control.*

Analyses for samples from both sites for years 2001 and 2002 (Figure 3.4-6) showed a very clear separation between the years. Samples clustered similarly within each year. Patterns observed in 2001 were again observed in 2002. Mud Hole samples divided into north and south groups in 2001 as well as in 2002. Additionally, station 2B at Little Tow also separated from the remaining stations in 2001. Again, no consistent differences in benthic community structure were discerned between samples collected from trawled verses control lanes. Analyses of individual replicates further support the trends seen in the analyses of combined replicates, showing the separation by year in both Mud Hole and Little Tow (Figures 3.4-11a.and b., Figure 3.4-12a. and b.). Ordination analysis further substantiates the trends seen in the clustering analyses (Figure 3.4-13 and Figure 3.4-14).

The community analyses established that the greatest dissimilarity in the benthic infaunal data occurred between years. Second, at lower levels of dissimilarity, Mud Hole samples separated *from Little Tow samples. Additionally, lower levels of dissimilarity reflected differences based on geographic locations and seasonality. Differences between control and experimental (trawled) sites were not discernable, and hence contributed the least variance to the data set.*

3.4.6 Faunal Changes in the Study Sites 2001 – 2002

Faunal densities and species richness were significantly lower at both Mud Hole and Little Tow in July 2002, compared to July 2001. In 2001, benthic grabs from the stations that were sampled in 2002, averaged 1433 individuals of 78 species. The 2002 samples had an average 836 organisms of 60 species. At Little Tow, densities were reduced from 1161 per sample in 2001, to 796 in 2002. Species richness declined from 75 species in 2001 to 63 in 2002. Density changes of this magnitude from year to year are not uncommon and have been seen in other longer-term studies in Massachusetts Bay (Michael and Ferraro, 2003, Maciolek et al. 2004). Inspection of the raw data (Appendix 3.4-A) indicates that the lower species richness in 2002 was due to the absence of a variety of rare species. Most of the dominants and mid–dominants were represented in both years. The caprellid amphipod, *Aeginina longicornis*, common at many stations (trawled and control) in 2001, was absent or present in much lower numbers in 2002. At control station (MH2B), 84, 52 and 49 specimens of *Aeginina* were collected in three different sampling events in July and August 2001. The same site yielded only 7, 3 and 3 individuals of this species in the July pre-trawl, and October and November post-trawl sampling events in 2002. Caprellid amphipods are epibenthic species found attached to algae or tubes and are vulnerable to physical disturbances. Changes in density could also be part of a natural cycle.

The overall reduction in both species richness and faunal densities between the years 2001 and 2002 is difficult to explain. Studies at other sites in Massachusetts Bay showed either no change in species richness and abundance for those years (Michael and Ferraro, 2003), or an increase (Maciolek et al. 2004). The loss of rare infaunal species and epibenthic species like caprellids, and a general reduction in overall abundance suggest possible disturbance. The study area was closed to groundfishing for the months of January – May 2002. It was not, however, closed to "exempt fisheries" such as shrimp trawling and scalloping and there is clear evidence of scallop dredge activity in the side-scan maps. After an area has been closed for a period of several months, fishermen often go into that area and fish intensively. This might have occurred in the study area during June. Since there is no documentation of the extent of trawling activity in the months before sampling for this study began in July 2002, the issue of an alternate disturbance factor cannot be addressed. Our 2002 study was originally to begin in April 2002 prior to the area opening, but issuance of the fisheries permit was delayed.

Long-term data sets for benthic infauna in similar sediments types found elsewhere in Massachusetts Bay are available from the MWRA outfall monitoring study (1992 – 2001) and the Gloucester 301(h) monitoring program (1990 – 2002). Benthic samples have been collected at several sites outside Gloucester Harbor twice a year since September 1990. The environment is similar to that of this study area. Sediments range from 8 to 30% silt/clay with a predominance of very fine sands. The depth is slightly shallower and ranges from 27 to 35 meters. Sampling methods in both studies are based on the use of a 0.04m^2 Ted Young grab with 0.5 mm sieving. Faunal composition in this study was very similar to that seen at stations in the Gloucester program over the last twelve years. The dominant species at all the sites near

Gloucester was *Prionospio steenstrupi*. A variety of other spionids were also common as was the bivalve *Nucula delphinodonta*.

The key factor in the Gloucester study is that there has never been any trawling through the sites. The stations are too close to shore. *The similarity in faunal composition between the regions (2001 report) suggests that trawling activity over the years at Mud Hole and Little Tow, or the additional trawling in this study, has not had a significant impact on the benthic infauna collected by these methods.* Minor differences in fauna between Mud Hole, Little Tow and Gloucester sites are due to sediment composition. Although they have similar silt/clay percentages, the modal grain size for Gloucester sediments is in the range of fine sands whereas Mud Hole and Little Tow are mostly medium sands. The study area is also more variable than Gloucester. The presence of larger particle sizes (medium sand and greater), serve as attachment sites for epibenthos which might contribute to the higher species richness seen at Mud Hole and Little Tow in 2001 (75 – 78 species per grab). Species richness in 2002 at Mud Hole and Little Tow were not statistically different from that reported for the Gloucester study over many years (54 – 67 species per grab).

Change in dominance from *Prionospio* to *Spio* from one year to the next and long-term changes in species richness and densities over the period 1992 –2002 have been documented in the MWRA Outfall Monitoring Program (Maciolek et al, 2004). In both the MWRA and the Gloucester outfall studies, the effects of disturbances due to major storms in the early 1990s is reflected in the benthic data as lowered species richness and densities. Other possible sources of differences are, variations in recruitment, long-term increases in the supply of organic matter to the benthos, and climatic change related to the North Atlantic Oscillation. The NAO index, exhibits a multiyear cycle with an average period of 8 – 10 years. Benthic infaunal communities off the west coast of Sweden have shown a cyclical pattern in abundance and biomass of 7 – 8 years (Tunberg and Nelson, 1998). This cycle appears to be related to climatic variability, which can affect primary productivity. Tunberg and Nelson suggest this may be a more important factor in benthic community structure than anthropogenic factors such as eutrophication. The same process could be a factor in Massachusetts and Cape Cod Bays.

3.4.7 Benthic Discussion

A large number of studies of the effects of trawling on the sea floor have been conducted, most of which have dealt with scallop dredges and beam trawls, which are heavier and have a greater impact on the sea floor. Conclusions have varied greatly from significant long-term impacts to very minor changes. Major factors contributing to the degree of impact are:

1) The energy of the environment

High-energy environments that are subject to frequent physical disturbance are inhabited by organisms adapted to such stress and the communities are therefore resistant to change and can recover very quickly (Brylinski et al. 200). Studies in low energy areas have documented faunal changes that have persisted for varying periods of time (e.g. Kaiser and Spencer, 1996, Sparks-McConkey and Watling 2001)

2) The type of gear used

Scallop dredges and older-style beam trawls are much heavier than modern otter trawls such as the one used in this study. The scallop and older-style beam trawls dig into the sea floor to a much greater depth creating a higher level of disturbance. Although some modern, lighter beam trawls have been designed, many still in use are heavier than otter trawls.

3) The intensity of trawling

Some studies have examined the effects of a limited number of trawls through an area and compared it with a control site, as in our 2001 study (BKAM and CR Environmental, 2003 for NOAA/NMFS). Others have taken a larger ecosystem approach and compared community structure in areas heavily trawled with those where the intensity of trawling is much lower or absent. Greater effects have been demonstrated in areas where trawling is heaviest.

In Monterey Bay, the epifauna and infauna of two areas subjected to different intensities of otter trawling were compared over a period of 3 years (Engeland and Kvitek (1998). The area with the highest trawl activity had lower densities of epifauna and most polychaetes, but higher densities of the poychaete, *Chloeia pinnata*, ophiuroids and opportunistic nematodes and oligochaetes. Their conclusion was that while high levels of trawling decreased bottom habitat complexity important for juvenile fish prey and their survival; the productivity of opportunistic species and other prey for adult fish was increased.

Tuck et al (1998) studied the effects of an otter trawl in a previously unfished, sheltered Scottish sea loch. This was a fine muddy habitat that had been closed for 25 years. The trawl was a modified rockhopper groundgear without a net, so there was no impact on epibenthic scavenger populations. Ten trawls were made on one day each month for 16 months. Significant differences in the number of species became apparent after 10 months and only returned to normal after 18 months of recovery. The trawled site had higher densities of infauna. An increase in the number of opportunistic species was mainly responsible for the differences in the communities. The bivalve *Nucula nitidosa* and polychaetes such as *Scoloplos armiger* and *Nephtys cirrosa* declined while other species seemed immune to the disturbance.

Jennings et al (2001) compared the effects of beam trawling on trophic structure in two regions of the central North Sea. Chronic trawling has led to dramatic reductions in the biomass of infauna and epifauna but there was no change in the mean trophic level of the community (as determined by nitrogen isotopes), or the relationship between the trophic levels of different size epifauna. There appeared to be two types of trophic structure. One where larger polychaetes feed on smaller species in a traditional food chain (e.g. Beukema 1987) and a second, where large bivalves and spatangoids (deposit and filter feeders) feed at lower trophic levels. Despite an order of magnitude decrease in the biomass of the infauna and a change from a community dominated by bivalves and spatangoids to one dominated by polychaetes, the mean difference was less than one trophic level.

The trophic structure of intensively trawled benthic invertebrate communities is maintained by those species with high intrinsic rates of population increase, which counteracts the mortality imposed by trawling. If the community is at the same trophic level, but biomass is lower, production must increase relative to biomass if the community is to use primary production at the same rate (Jennings et al. 2001)

Trawling conducted in this study at Mud Hole and Little Tow in 2001 and 2002 failed to produce any significant changes in density, species richness, or species composition of the benthic infaunal community. Significant differences were attributable to years (2001 versus 2002), sites (Mud Hole versus Little Tow), season, and geography. The lack of impact was probably due to a combination of the type of gear used, intensity of trawling, and the energy of the environment. There may have been impacts on other components of the ecosystem that simply could not be assessed by the methods used here or the scale of the project. The question posed is what intensity of trawling would be necessary to produce measurable impacts on the benthic infauna in this environment.

Clearly defined effects of trawling on large sessile epifauna, particularly from harder substrates, has been demonstrated in a variety of studies. The significance of the loss of larger epifaunal species, as demonstrated in some studies, with a corresponding increase in productivity by smaller opportunistic species needs further investigation. Two approaches might be taken to further our understanding. One is a detailed investigation of the changes in productivity resulting from trawl disturbance. Trawling effects have not been examined across quantifiable gradients of disturbance (Collie et al. 1997, Kaiser et al. 2000). Another is a more ecosystem oriented approach, which would evaluate the significance of changes in epifaunal abundance to overall habitat structure and productivity, and the importance of microhabitat changes for fish populations.

3.5 REMOTS Survey Results and Discussion

The sections which follow (3.5.1 through 3.5.3) are excerpted unmodified from SAIC Report Number 634 by R. Valente and N. Pinckard. Appendix 2.7-A provides methods, and a CD-ROM of the original report has been provided to NOAA/NMFS. Note that the SPI work was conducted prior to the major November storm. Donald C. Rhoades, Ph. D., has provided discussion and comment on this report (Section 3.5.4).

3.5.1 Baseline Characterization of the Little Tow Area

The results of the August survey to characterize "baseline" conditions at the trawl lane and control lane stations in the Little Tow area are summarized in Table 3.5-1. Representative images illustrating these baseline conditions are provided in Figure 3.5-1. Overall, there was little difference between the trawl and control lane stations in the basic physical and biological characteristics of the surface sediments. The surface sediments at all of the Little Tow stations consisted predominantly of muddy very fine sand, having a grain size major mode of either 4 to 3 phi (very fine sand) or 3 to 2 phi (fine sand; Table 3.5-1 and Figure 3.5-1).

The amount of mud (i.e., silt-clay) mixed with the fine sand appeared to be somewhat variable among the stations. Stations with higher apparent amounts of silt-clay appeared to have a finer texture in the sediment-profile images and were assigned a grain size major mode of 4 to 3 (very fine sand), while stations with lower apparent proportions of silt-clay had an obvious coarser texture and were assigned a grain size major mode of either 3 to 2 phi (fine sand) or 2 to 1 phi (medium sand). Reflecting these grain size differences, the benthic habitat classification at the Little Tow stations was primarily either UN.SS (unconsolidated sediment consisting of very fine sand mixed with silt-clay) or SA.F (uniform fine sand; see Appendix 2.7-A) for a more detailed description of these benthic habitat types).

The REMOTS camera penetration values provide an indication of the relative compactness of the sediment; these values have a possible range of 0 to 21 cm (i.e., no penetration to full penetration of the sediment-profile camera prism into the sediment). The average values of around 5 cm at the Little Tow trawl and control stations (Table 3.5-1) are at the lower end of the range and reflect the relatively compact nature of the fine sand sediment.

Boundary roughness is measured in the sediment-profile images as the vertical difference in centimeters between the high point and low point of the sediment surface in contact with the camera's faceplate. This measurement provides an indication of the amount of small-scale relief (i.e., roughness) that exists at the sediment surface across the 13-cm width of the faceplate. The average boundary roughness value at both the Little Tow trawl and control stations was only 1.1 cm, with a range from 0.8 to 1.7, indicating that the sediment surface had relatively little small-scale relief or "microtopography".

The apparent Redox Potential Discontinuity (RPD) is determined in REMOTS images based on the contrast between lighter-colored, aerobic surface sediments and darker, reduced/anoxic underlying sediments. The depth of the RPD provides a measure of the degree of biologically-mediated oxygen penetration (i.e., aeration) of the sediment surface. The average RPD depths of 2.3 and 2.6 cm at the trawl and control stations, respectively, generally indicate good sediment aeration and a moderate-to-high degree of biogenic sediment mixing (Table 3.5-1).

The sandy surface sediments at the Little Tow stations appeared to be inhabited by a benthic community dominated by surface-dwelling, tube-building polychaetes (Stage I). The images at many of the Little Tow stations had numerous tubes of these organisms visible at the sediment surface (e.g., Figure 3.5-1). A small percentage of the images also showed evidence of larger-bodied, deeper-dwelling benthic organisms (Stage III) underlying the Stage I surface tubes (e.g., Figure 3.5-1, image A). This resulted in the assignment of a “Stage I on III” successional status to these images (Table 3.5-1). The average OSI values were +5.2 and +5.6 for the trawl and control lane stations, respectively. These are intermediate values that reflect the dominance of the lower-order successional stage (i.e., Stage I) that is commonly found in a sandy benthic environment.

3.5.2 Baseline Characterization of the Mud Hole Area

The results of the August baseline survey at the trawl and control stations in the Mud Hole area are summarized in Table 3-2. In general, the surface sediments in the Mud Hole area were similar in appearance (i.e., color and texture) to those in the Little Tow area. These sediments consisted predominantly of muddy very fine sand, having a grain size major mode of either 4 to 3 phi (very fine sand) or 3 to 2 phi (fine sand; Table 3.5-2 and Figure 3.5-2). Reflecting these grain size characteristics, the benthic habitat classification at the Mud Hole stations was primarily either UN.SS (unconsolidated sediment consisting of very fine sand mixed with silt-clay) or SA.F (uniform fine sand; Table 3.5-2).

The average camera penetration values at the Mud Hole stations (6.3 and 6.9 cm) were slightly deeper than those at the Little Tow stations, suggesting a slightly softer texture attributed to higher apparent amounts of silt-clay at a greater percentage of the Mud Hole stations. The average boundary roughness values at the Mud Hole trawl and control stations were less than 1.4 cm and similar to those at the Little Tow stations, again indicating that the sediment surface had relatively little microtopography. Likewise, the average RPD depths at the Mud Hole stations were comparable to those at the Little Tow stations, indicating good sediment aeration and a moderate-to-high degree of biogenic sediment mixing.

Similar to the Little Tow area, the sandy surface sediments at the Mud Hole stations appeared to be inhabited by a benthic community dominated by surface-dwelling, tube-building polychaetes (Stage I; Figure 3.5-2). A small percentage of the Mud Hole images also showed evidence of larger-bodied, deeper-dwelling benthic organisms (Stage III) underlying the Stage I surface tubes, resulting in the assignment of a “Stage I on III” successional status to these images (Table 3.5-2; Figure 3.5-2 image A). The average OSI values at the Mud Hole stations were likewise similar to those at the Little Tow area.

3.5.3 Evaluation of Trawling Effects in the Little Tow and Mud Hole Areas

The results of the October REMOTS survey are summarized in Table 3.5-3 for the Little Tow stations and Table 3.5-4 for the Mud Hole stations. Likewise, the results for the November survey are summarized in Table 3.5-5 for the Little Tow stations and Table 3.5-6 for the Mud Hole stations.

Among the changes that might be expected to occur if trawling was physically disturbing the sediment surface are the following: 1) breaking up of the otherwise cohesive sediment particles that would be manifested in the sediment-profile images as a noticeable change in the sediment texture or fabric, 2) increase (or decrease) in the amount small-scale surface roughness, 3) a decrease in the RPD depth resulting from removal of the oxidized surface layer of sediment, 4) significant breakage or removal of delicate biological surface structures (e.g., polychaete tubes), and 5) consistent with 3 and 4, apparent changes in infaunal successional stage or OSI values.

Overall, the images obtained in the both October and November post-trawl REMOTS surveys showed an absence of any significant trawling-induced changes in either physical or biological conditions at the sediment-water interface. A statistical test for unplanned comparisons among pairs of means (Games and Howell method at the 0.05 significance level, from Sokal and Rohlf (1981)) indicated no significant differences among surveys or station groups in the average boundary roughness, RPD, or OSI values shown in Tables 3.5-1 through 3.5-6. In other words, in any particular survey, there was no significant difference in each of these three parameters between the control lane versus trawl lane stations. Likewise, there was no statistically significant change *through time* in each of these parameters at either the trawl or control stations.

Figures 3.5-3 through 3.5-7 present representative REMOTS images illustrating the absence of any detectable changes in sediment fine-scale characteristics, either through time or in terms of the “trawl versus control” comparison. In all cases, there were no obvious, consistent changes in the basic color, texture or fabric of the sediment surface that would otherwise indicate physical disturbance by trawling.

The density of tube-building, Stage I polychaetes is a somewhat less reliable indicator of trawling disturbance than sediment texture or RPD depth, because populations of these opportunists are known to have considerable natural variation in both space and time. Even if trawling was resulting in wholesale removal of these tubes across wide areas, these organisms are capable of re-establishing populations within days. In a few of the images, there were Stage I tubes that appeared to be lying flat (i.e., recumbent) on the sediment surface rather than in the more typical upright position, but there was no consistent pattern in the occurrence of these recumbent tubes between trawl versus control stations to signal clearly a trawling effect. Although Stage I tubes are able to become quickly re-established following a physical seafloor disturbance, the persistence of these tubes through time *together with* the absence of any other indicators (e.g., removal of the oxidized surface layer, changes in surface texture or microtopography) supports the conclusion that trawling did not result in any appreciable changes in sediment physical or biological characteristics, to the extent such changes could be determined through repeated sediment-profile imaging surveys.

3.5.4 Sediment Profile Imaging Discussion (Donald C. Rhoads)

3.5.4.1 Physical evidence of trawling impacts

The REMOTS® survey of 2002 did not detect any clear difference between the two trawled sites and their respective control areas (Little Tow and Mud Hole). The sediment-profile images show that, within the small field-of-view provided by the camera, (ca. 13 cm wide and ca. 20 cm high), the sediment-water interface is dominated by biogenic roughness (feeding mounds, pits, etc) rather than physically induced roughness such as door furrows, net sweep, erosion, or physical mounding. Ecologically significant gear impacts would be expected to result in significant surface erosion removing all, or part, of the surface oxidized zone as well as exhumation and/or burial of near surface –dwelling infauna. Such erosion produces anomalously thin apparent RPD zones relative to the ambient bottom and exposes reduced sediment to the sediment-water interface.

Larger scale panoramic imaging survey systems used in this study (i.e. side-scan sonar and ROV videos) clearly show the presence of plowed furrows related to the passage of trawl doors along the bottom. It is highly likely that random deployment of the REMOTS® optical system at only 6 stations (with 3 replicates per station) in the trawled areas did not sample the trawl door furrows and associated lateral mounds. It is likely however, that these REMOTS® stations either were located in “control-like” areas of the bottom not affected by recent trawling or were located in areas that were passed over by the ground cables and trailing net (i.e. “cookies” and net sweep). If the latter case is true, the passage of the ground cables/net did not leave a disturbance signature that could be detected by high resolution REMOTS® imagery.

3.5.4.2 Biological evidence of chronic bottom disturbance

The Organism Sediment Index (OSI), calculated from the component REMOTS® parameters, has empirically proven to be a sensitive indicator of existing or past bottom disturbance based on REMOTS® surveys conducted in a variety of marine habitats around the world over the past two decades. The overall population means for OSIs at Little Tow and Mud Hole trawled sites range from 5.3 t0 5.7 and the OSI values for the control sites range from 5.4 to 6.2 (Valente and Pinckard (2003). Experience has shown that OSI values of +6 or greater tend to be associated with low level or infrequent physical/chemical impacts while values less than +6 tend to be associated with impacted areas. Severely impacted areas yield OSIs that are negative. No negative OSIs were measured in this study, Mean values for both trawled and control areas are comparable in value being just below the +6 threshold criterion. This suggests that the ambient system is experiencing a low level of ambient disturbance. Results of the side-scan and ROV surveys show that parts of the bottom are rippled indicating that bottom currents are sufficiently strong to produced bed-load transport of medium to fine sand. In addition, the ROV video shows high levels of suspended fine-grained sediment. The source of this likely to be resuspended organic-mineral aggregates producing a near-bottom turbidity zone. Such benthic turbidity zones (BTZs) are known to be driven by tidal turbulence and are characterized by high ambient resuspension rates (Rhoads, et al., 1984). It is likely therefore that the impact on the bottom by the trawl's ground cables /net sweep is comparable to natural seabed disturbance induced by sediment bed load transport of sand and tidal resuspension of fine fractions.

Because we believe that none of the REMOTS® images were located within the trawl door tracks as observed in side scan and ROV images, the question remains as to the impact of this more extreme disturbance on the benthic fauna. Although door furrows associated with a single trawl pass are only approximately 1-2% of the total trawl footprint, this does not necessarily mean that the overall cumulative impact is ecologically trivial. For example, furrows and depressions are known to focus foraging search patterns by certain benthic or demersal consumers along these topographic features (Burrows, et al. 2003).

3.5.4.3 Results of European trawl impact studies using SPI technology

Insight into the effects of trawl door furrows on the benthic environment, while not addressed in our Massachusetts Bay REMOTS® survey, can be provided by European studies on bottom trawl effects using the same profile imaging technology (REMOTS® sediment profile imaging used in this study is a registered trademark owned by SAIC. This same technique used by other entities is generically called sediment-profile imaging or SPI).

Three SPI surveys of experimentally trawled bottom areas in Europe provide a basis of comparison with the results of our Massachusetts Bay study: The Gullmarfjiord in Western Sweden, The Gulf of Lions off the Rhône River mouth, and the Gulf of Iraklion in the Aegean Sea on the north coast of Crete.

The Gullmarfjiord study is particularly interesting as it was done after the study area was protected from shrimp trawling for 6 years. This hiatus provided an excellent baseline for comparison with experimental trawling impacts (Nilsson and Rosenberg, 2003). The experimental area was randomly subdivided into three control and 3 trawling transects; each ca. 1.5 km long. The bottom mud was located in water depths of 75 to 100 m. All transects were sampled three times in 1996 prior to trawling and three times in 1997 after trawling. Ten (10) replicated SPI images were randomly taken at each sampling event. Trawling was done using 80 x 140 cm (125 kg) trawl doors with a 14 meter-long (20 kg) ground rope. A distance of 30 meters separated the trawl doors.

In this study, forty-three percent (43%) of the SPI images showed recognizable mechanical disturbance including trawl door furrows, which were about 10 cm deep and 30 to 60 cm wide. These same images showed a decrease in a Benthic Habitat Quality (BHQ) index relative to control transects. The BHQ index, as developed by Nilsson and

Rosenberg, 1997, ranges from 0 (severely impacted) to 15 (undisturbed). Although the BHQ index is scaled differently than the Organism-Sediment Index (OSI) used in our Massachusetts Bay study, both indices include some common organism-sediment relationships. Before trawling, the BHQ population mean for the Swedish study ranged from 10 to 12. After trawling, the BHQ index declined by 25% at impacted transects and 4% at control transects.

The same trawling gear used in the Gullmarfjiod study was also used in an experimental trawling experiment in the Gulf of Lions off the Rhône Delta (Rosenberg, et al., 2003). However, no information about trawling history was available and so the status of a control area is in question. However, 30% of the images showed evidence of otter door furrows and associated mud clasts ("rip-ups") resting on the sediment-water interface. Physical disturbance of the bottom was considered to be comparable to that observed in the Swedish study (Nilsson and Rosenberg, 2003).

The Aegean Sea trawling study near the Isle of Crete consisted of control areas, which were spatially separated from trawled areas. Two types of bottoms were trawled; a 200 meter-deep mud bottom and an 80 meter-deep carbonate-rich bottom that was more compact (hard) than the deep-water mud (Smith et al., 2003). Two hundred and eighty two (282) SPI images were taken in this study. Because this part of the Aegean Sea is oligotrophic, benthic biomass and abundance is low, hence, SPI images did not show much direct visual evidence of eipfauna or infauna. This fact precluded calculating a BHQ or OSI index for each image. Instead, the study recognized up to 32 sedimentary attributes (both physical and biogenic) that were used in a multivariate analysis of trawled versus control stations. In addition, univariate analysis was applied to data on camera prism penetration depth (a surrogate measure of bottom hardness) and boundary roughness.

The Aegean study concluded that there was a clear difference between trawled and control sites. A first-order impact of trawling was production of high spatial variance in the measured sedimentary attributes and, because of this variability; high station (image) replication was required to adequately sample this variability (the authors suggest that up to 30 images per station per sampling event would be necessary for characterizing this patchiness).

In summary, all of the European experimental trawling studies showed clear evidence of physical impact on the bottom and that most of this disturbance was related to door furrows and associated gouging, rip-ups, and erosion. The relative absence of evidence of severe benthic impacts in our Massachusetts study may be related to the low number of stations and replicates used to sample the system.

3.6 Fisheries Survey Results

3.6.1 Trawl Catch Results

A total of fifteen fish species and six invertebrate species were identified from the trawl catches during the three experimental trawl surveys in early August (pre-chronic trawling), and October and November (post-chronic trawling) at the Mud Hole and Little Tow sites. Refer to Table 3.6-1 for a list of the fish and invertebrate species caught during the 2002 trawl study.

To help interpret the catch results from the experimental trawling surveys at Mud Hole and Little Tow, the data were viewed in several different formats:

- Tables of Catch by Species in kg per Tow (Table 3.6-2);
- Graphs of Overall Catch (Figure 3.6-1), and Average Catch per Tow (Figure 3.6-2), and Catch Composition for Mud Hole and Little Tow trawled lanes (Figure 3.6-3);
- Graphs of Densities (weight in kilograms per 1000 square meters) based on weight of major demersal species caught and the area swept during each tow (Figures 3.6-4, 3.6-5, 3.6-6);
- Graphs of Species Density (numbers per 1000 square meters) based on numbers of major species of commercially targeted flounder caught, and the area swept during each tow (Figure 3.6-7);
- Length frequency distributions of target species, winter flounder and yellowtail flounder, at Mud Hole (Figures 3.6-8 and 3.6-9) and Little Tow (Figures 3.6-10 and 3.6-11);

Seasonal trends over the study period are clearly seen in the catches sampled during each of the experimental trawl surveys (Figures 3.6-1 and 3.6-2). In general, flounder and skate abundance increases in the fall, as the rock crab abundance declines. Spiny dogfish are found sporadically throughout the study period. Many species are present, such as Atlantic cod, windowpane flounder, American lobster, and squid, but due to their low densities, little can be said about their abundance or movements. Focus was placed on bottom feeding commercially important demersal finfish, targeted by otter trawling. Yellowtail flounder and winter flounder were the most closely studied, being predators on benthic infauna and having sufficient numbers to provide an adequate data set.

The entire catch of these flatfish were sorted, weighed and measured. A subset thereof had their stomachs removed and preserved individually for identification of their contents (see Section 3.6-2 below).

Mud Hole

During the experimental trawl surveys, the dominant finfish species at Mud Hole were *spiny dogfish, yellowtail flounder*, and *winter flounder*. *Skate, crab* and *monkfish* were also an important component of the catch (Figure 3.6-3).

Mud Hole, Lane 1 and Mud Hole, Lane 3 show similar trends over the study period. *Yellowtail flounder* catch increased over the study period at both Mud Hole trawl lanes. Mud Hole, Lane 1 showed a greater rate of increase during the August to October period while Mud Hole, Lane 3 had a greater rate of increase between October and November. *Winter flounder* catch increased from August to November, but shows less of an increase at Mud Hole, Lane 1 (Figure 3.6-4).

Skate were more abundant at Mud Hole, Lane 1 over the study period and were most abundant in November for both trawled lanes. The *rock crab* population declined over the study period but peaked in October at Mud Hole, Lane 3; whereas, a steady decline was observed at Mud Hole, Lane 1. *Monkfish* abundance remained relatively low throughout the study period dropping to zero at both trawled lanes in October.

Spiny Dogfish, although not targeted for commercial fishing due to regulations, was a dominant component of the total catch on both trawl lanes. In August, Mud Hole, Lanes 1 and 3 had comparatively low densities of spiny dogfish. However, the October experimental tow at Mud Hole, Lane 3 resulted in a density of 291 kg/1000m^2, 4.5 times the next highest density of 64.5 kg/1000m^2 at Mud Hole, Lane 1 on the same date (Figure 3.6-6). This one tow had a density greater than all other tows over the study period combined (Photograph 2.2-1).

Little Tow

Similar to Mud Hole, the catch at Little Tow was predominantly *yellowtail flounder, winter flounder*, *crab*, *skate*, *monkfish* and *spiny dogfish.* Finding trends at the Little Tow study area is somewhat confounded by the fact that no data is available for Little Tow, Lane 3 on November 9, 2002, due to a gear conflict. Lobster gear set along the lane made trawling impossible in November.

Yellowtail flounder and *skate* catch increased over the study period with yellowtail density reaching its peak of 3.9 kg per 1000m^2 in November (Figure 3.6-5). *Winter flounder* densities remained low at both Little Tow lanes, reaching a peak of only 0.76 kg/1000m^2 in October at Little Tow, Lane 1.

Water temperature is a factor influencing the movement of yellowtail flounder. During the spring, yellowtail flounder in Massachusetts' inshore bottom trawl surveys are most frequently found in waters of 5 to 9 degrees C. Similar fall trawl surveys find yellowtail most abundant in waters of 9 to 11 degrees C (NOAA-NMFS Essential Fish Habitat Source Document). This seems congruent with our finding that the highest densities for yellowtail flounder were in November when bottom water temperatures were about 10.5 degrees C. It is interesting to note that as the surface water temperature decreased, bottom water temperatures actually increased over the study period due to mixing of the water column. The beginning of this fall mixing can be seen in the October CTD data. Mixing is then complete in November, most likely due to the storm.

Rock crab catch and densities at Little Tow were very similar to those for Mud Hole rising slightly from August to October then falling off in November. *Monkfish* were only present at a significant density in August at Little Tow, Lane 1 (2.57 kg/1000m^2) then decline sharply to 0.23kg/1000m^2 in October, and were not present in November.

In August 2002, Little Tow station densities for *spiny dogfish* were slightly higher than those seen at Mud Hole but dropped to almost zero in October and stayed low through November.

3.6.2 Flatfish Metrics and Stomach Content Results

Refer to Figures 3.6-8 to 3.6-11 for length frequency distributions for yellowtail flounder and winter flounder at Mud Hole and Little Tow. The yellowtail and winter flounder catch ranged from 16 to 41 cm in length. The length frequency distribution of yellowtail flounder indicate that the catch was dominated by an age class of two-year-old fish with a mean size of about 33 cm in August, increasing to 34 cm in November. This increase shows growth over the study period. A few one- and three-year-old fish are present as well (NOAA-NMFS EFH source documents). Winter flounder showed a similar shift from about 9 cm to almost 33 cm, again showing dominance of a second year age class.

The purpose of assessing the stomach contents of the targeted bottom feeding fish, winter flounder and yellowtail flounder, was to:

- Document the diets of these flatfish within the study sites considered Essential Fish Habitat (EFH);
- Determine how the flatfish prey selection may relate to the benthic fauna; and
- Explore the potential effects of repeated towing on consumption or diet.

Feeding by *yellowtail flounder* is generally restricted to benthic macrofauna. Annelids and arthropods found on the sediment surface constitute large components of the yellowtail flounder diet. For yellowtail flounder above 5 cm in length, other invertebrates and fish (e.g., capelin and sand lance) make up most of the remainder. Among crustaceans, amphipods are the largest diet component.

Winter flounder are generalists that feed on any prey of suitable size encountered while foraging. Adults have little variation in diet with size. Mouth size is even more restrictive than in yellowtail. Polychaetes, crustaceans (amphipods and decapods) and mollusks (bivalves) are identified as important prey by percent incidence and weight for studies in the Gulf of Maine. Polychaetes were frequently the most important food item on a percent weight basis and in terms of numbers (Langton and Bowman 1981). Cnidaria have also been found to be an important component of the adult winter flounder diet

(Langton and Bowman 1981). Other food items include fish eggs, small fish and vegetation (nearshore).

The size ranges of the targeted flatfish from which stomachs were collected in this trawl study were similar between species and study sites, about 20 to 40 cm. Stomachs of yellowtail and winter flounder adults from pre-trawl surveys in August, and post-chronic trawl surveys in October and November were first sorted into broad taxonomic categories: annelida, crustacea, molluscs, other invertebrates and unidentifiable stomach matter.

Some 68 different taxa were identified from fish stomachs. The average density of taxa collected in yellowtail and blackback flounder stomachs at Mud Hole are listed in Tables 3.6-3 and 3.6-4 and those for the same species at Little Tow in Tables 3.6-5 and 3.6-6. Raw counts are tabulated in Appendix 3.6-A.

Tables 3.6-7 and 3.6-8 list the 10 most dominant species collected in benthic grab samples from the experimental lanes and compares these with the most abundant taxa found in the stomach of fish collected during the same survey period. The August stomach contents are compared with July benthic infaunal samples. In early August, there was very little material in the fish stomachs. This might have been related to time of day or the tide. Handling procedures were the same for all surveys and it appears that the fish had not been actively feeding just before the trawls were taken. There was an average of 14.4 to 16.8 individuals of 3.5 to 6.8 species. At Mud Hole, spionids, probably the species *Prionospio steenstrupi* and *Spio limicola,* were the most abundant organisms in stomachs of yellowtail. All the remaining species groups listed were polychaetes. For blackbacks, maldanids were the most common prey followed by spionids. The remaining most common species in the stomachs were all polychaetes with the exception of cerianthids. Since these anemones were not common in the benthic faunal samples there must have been some specific selection for this taxon.

At Little Tow, spionids were the most common prey followed by cirratulids and caprellids. Caprellid amphipods were not common in the benthic samples in 2002. In 2001, the caprellid, *Aeginina longicornis,* was present in much greater numbers and was an important component in stomach contents. Spionids were the most numerous group eaten by blackback flounder followed by aorids, another amphipod taxon, which was found in fewer numbers in 2002, partly because sites selected for study were those with finer sediments. Aorids are more abundant on coarse sediments. The bivalve *Nucula delphinodonta*, was not listed among the dominants in stomach content analyses although it was always among the most numerous species at all sites in each sampling period. Although it is a small bivalve, it is large relative to spionoid polychates and was reported in the stomachs of both yellowtail and blackback flounder in low numbers.

In October, average numbers of individuals in fish stomachs ranged from 57.7 to 225.6 and the average number of species was 12.5 to 20.5. Spionids were the most numerous taxon consumed at both Mud Hole and Little Tow. Most of the remaining prey items were polychaetes with cirratulids, maldanids, ampharetids and phyllodocids very common. The hemichordate, Phoronis, was among the dominant prey for yellowtail. Three groups of amphipods (caprellids, phoxocephalids and ampeliscids) were important food items at Mud Hole for blackbacks. At Little Tow aroids were again among the dominant prey.

November stomach contents were dominated by spionids except for blackback flounder from Little Tow. The average number of organisms found was 47.4 to 443.6. Numbers of species present ranged from 9.0 to 25.7. Cerianthid anemones were the most common prey for blackbacks at this site and in many cases stomachs were filled with a few large individuals of Cerianthus, leaving little room for anything else. Additional common prey items were ampharetids, cirratulids and phoronids. Cerianthids, which can grow to a large size were almost absent in the diet for yellowtail, which have smaller mouths. There was fairly good comparison between the species listed as dominants in the benthic grab samples and those found in the stomachs of flounders. Spionids were abundant in both cases. Phoronids were more abundant in October and November benthic sampling events and they became more common among the prey items. There are other taxa for which there seem to have been some selectivity because they were found among the dominant components of the stomachs but not in the grab samples. Some of these species might have been present in good numbers in grab samples but their relative numerical dominance was greater in fish stomachs. Such taxa include flabelligerids and lumbrinerieds (polychaetes). Others, with low densities in infaunal samples, were among the dominants in stomach analyses; e.g. caprellids, aorids, ampeliscids and phoxocephalids among the amphipods, and the anemone *Cerianthus*.

The total number of individuals (abundance) and numbers of species (richness) found in yellowtail and blackback stomachs were compared (Table 3.6-9) and tested for significant differences. With the exception of the August survey when very little material was found in any of the stomachs, the number of organisms found in yellowtail stomachs was significantly higher than found in blackbacks. Species richness was also significantly higher in yellowtail stomachs than in blackbacks except in August. Yellowtail with their small mouths, apparently select smaller, more abundant organisms as their food supply, and a wider variety of species. Blackback flounder are able to select larger, less abundant species as a significant component of their diet. They do however also consume many of the small polychaetes that are the staple of the yellowtail diet.

4.0 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

4.1 Disturbance and Ecological Structure

The Massachusetts Bay trawling impact study has addressed the impacts of trawling on physical attributes of the seabed and on diversity, abundance, and successional status of the benthos. Results of our studies in 2001 and 2002 indicate that impacts of net sweep and the ground cables are not great relative to untrawled reference areas. Local impact of trawl door furrows remains moot as the REMOTS® survey apparently did not sample these features. Faunal data also indicate that there were no great differences between trawled and "control" (reference) areas in terms of physical or ecological structure of the seabed. The ambient benthic infauna is adapted to natural disturbance in the form of bed-load transport of sand and the resuspension of fines by tidal turbulence. It is likely that the impacts of trawling on the infaunal benthic communities at Mud Hole and Little Tow are comparable in magnitude to these natural disturbances. This assertion may not hold true for trawl door furrows as these features, although a small proportion of the impacted bottom, were not adequately sampled.

4.2 Disturbance and Ecological Dynamics

The 2001 and 2002 trawling studies have focused on seafloor bathymetry, sedimentary structures, benthic invertebrate and fish inventories, and fish stomach contents. Rate dependent processes were not addressed. Any deeper understanding of the effects of trawling will require information about these rate sensitive processes. For example:

1.) *What are the rates of infaunal recovery (rate of arrival of colonizing individuals and species per unit time) in disturbed bottom areas affected by both natural and trawling disturbances?*

2.) *How do these disturbances impact secondary productivity of the bottom (change in prey biomass per unit area per unit time)?*

If these two questions can be answered, one may be able to determine (in advance) the upper rate of trawling that a site can sustain without compromising bottom secondary productivity.

The ecological impact of trawling on the benthic infauna, as described in our Massachusetts Bay study and those cited from Swedish waters (Nilsson and Rosenberg, 2003) and the Mediterranean (Rosenberg, et al., 2003 and Smith, et al., 2003), indicate that disturbance by trawling does not cause total mortality of the impacted areas. Rather, near surface-dwelling organisms tend to be more severely impacted than deeper-living species. By definition, faunal recovery therefore takes place as a secondary succession (primary succession involves repopulation of a substratum representing competition-free space).

The rate and mode of recolonization and succession is scale-dependent and also is affected by the kinetic energy of the ambient bottom (McCall, 1977 and Whitlach, Lohrer, and Thrush, 2003). Small-scale disturbances such as anchor scars, trawl door furrows, predator foraging pits, etc., can be very rapidly recolonized on a scale of hours to days by immigration of juvenile/adult organisms from the adjacent ambient bottom (i.e. non-larval recruitment). This is especially effective if the process of immigration is assisted by advective processes such as tidal or wind wave turbulence and bed-load transport of sediment and associated organisms (Whitlach, Lohrer, and Thrush, 2003). The non-larval mechanism for recolonization involves the redistribution of pre-existing biomass from the ambient bottom to the impacted area and only impacts secondary productivity in terms of a slight overall dilution of biomass per unit area.

Larval recolonization, on the other hand, results in the arrival of new individuals and can locally significant increase secondary productivity over ambient (i.e. undisturbed) bottom areas. Larval settlement can be highly focused on disturbance patches especially if there is a positive feedback from sediment chemistry to these larvae (e.g. the "suphide cue" as described by Cuomo (1985) for settlement of *Capitella* larvae as well as other cueing factors involving sediment geochemistry as enumerated in Nilsson and Rosenberg, 2003.

4.3 The Relationship Between Disturbance and Productivity

It is well documented in terrestrial systems that natural disturbances such as forest or prairie fires, windfalls, and periodic flooding result in an increase in overall productivity over pre-disturbance conditions. Man-made disturbances such as plowing, forest cutting, slash and burning, and flooding also result in enhanced productivity. Odum (1969) points out that pioneering seres that consist of rapidly colonizing and growing species are more productive than mature seres consisting of temporally stable and slow growing mature species. Odum (1969) further states that systems that experience "pulsed" disturbance are, over the long term, the most productive because ecological succession is arrested, i.e. kept in a constant state of exponential recruitment and growth. The optimal frequency for pulsed disturbances in terms of our sustaining and enhancing production is unique for each subsystem of interest. If pulsing is too rapid, successful recolonization may be compromised. If pulsing is too infrequent, the system may become dominated by later colonizing and slow growing species. Environmental management of natural and cultivated systems revolves around understanding the optimal pulse rate for specific systems.

The application of Odum's pulse-stability concept to aquatic systems has lagged behind that of terrestrial ecology, especially as applied to secondary productivity. One of the first estuarine studies to address this issue was described in Rhoads, McCall and Yingst (1978) regarding disturbance and (secondary) production in Long Island Sound. That study was based on both experimental and observational studies of recolonization of dredged material deposits by both larval and non-larval colonization. The authors noted that disturbed habitats, involving primary succession, were between 2 and 6 times more productive than the ambient sea bottom. In retrospect, these productivity estimates were probably low as the studies involved sampling the macrofauna with a one-millimeter mesh sieve. Early arriving pioneers, because of their small size, tend to pass through such a coarse mesh sieve and therefore were not included in the data.

What is the Optimum Frequency of Trawling to Sustain or Enhance Benthic Secondary Productivity?

We have noted from our Massachusetts Bay trawling study that there is no difference between the species composition in trawled and "control" (reference) lanes of Little Tow and Mud Hole. This suggests that both the trawled and reference lanes are in approximately the same successional stage reflecting the long term ambient disturbance frequency. An inspection of the benthic species list reveals that two of the faunal dominants (*Prionospio steenstrupi* and *Unciola inermis*) are important food items for bottom fish and that overall faunal density is slightly higher in the trawled lanes than in the controls. *What if the trawling frequency was doubled or tripled? Would this frequency of "pulsing" be accompanied by enhanced productivity of both the invertebrate prey species and increased net catch?*

4.4 A Modeling/Simulation Approach

Field experiments involving manipulated pulsed disturbances and associated ground-truth sampling can be very expensive. For this reason, we recommend that before such a field effort is made, modeling/simulation studies be conducted to provide insight into the pulse frequency to maintain or optimize secondary benthic productivity. Examples of such modeling exercises are given in McCall (1975, 1977), Rhoads, McCall, and Yingst (1978), Whitlach, Lohrer, and Thrush (2003), and Zajac (2001). This type of modeling is based on knowledge of the dominant colonizing species life history attributes, literature values for known recolonization rates, and seasonal affects on somatic/population growth rates and recruitment.

We suggest that the STELLA graphical program used by Whitlach, Lohrer, and Thrush (2003) to simulate the recovery time for benthic systems colonized by larval and non-larval recruitment may serve as a platform for the modeling and simulation proposed here. Some additions and reconfigurations would be required in their STELLA program to address the critical trawling frequency problem. The model (or family of models) would need to address a wide range of management scenarios. For example, the simulation should be sensitive to the targeted fish population (s) and hence the preferred benthic prey species eaten by the fish populations interest. The input variables to the simulations would include how frequently the system is impacted by natural disturbances known to be important in restructuring the benthos such as storm reworking, seasonal hypoxia, or major fluctuations in salinity. The response of benthic prey to such disturbances will also depend on the candidate species pool that can populate the site. This includes the method and frequency of each species' mode of reproduction, dispersal, and fecundity. Finally, the model must consider the effect of seasonal water temperatures and primary production cycles that drive recruitment and growth.

For this initial modeling effort, we suggest that the simulation be run for two sites representing end members in terms of ambient disturbance. The first would be Little Tow/Mud Hole representing a naturally disturbed bottom (seasonal storm induced bed load transport). This simulation will rely on data already in hand in our 2001 and 2002 trawling impact studies. A second simulation would be run representing a low kinetic energy site in Massachusetts Bay (off Gloucester per Alan Michael's suggestion or a high successional stage mud site in central Mass Bay where several years data from the MWRA study is available). The two simulations would provide insight into the critical pulse disturbance in areas naturally affected by storm reworking (Little Tow and Mud Hole) versus a low kinetic energy bottom which is maintained in a high order successional stage. Seasonality factors would be able to be held constant given the proximity of the two sites.

The product of such a modeling exercise would be bivariate graphs of disturbance frequency versus secondary productivity over an annual cycle for both sites. Based on this simulation effort, the critical pulse disturbance would be identified for the two fishing sites. This would include estimating the theoretical upper limit of trawling frequency that would compromise secondary productivity and the optimal trawling frequency for maintaining the bottom in a state of exponential recruitment.

A Phase II study would include a field verification program to test the validity of the model predictions. This approach could provide important management insight into optimizing demersal fishing frequency in the New England coastal zone at two end-member sites and provide a protocol for extending the approach to other areas of EFH management interests. It is likely that the theoretical model outputs proposed here would be directly useful for Massachusetts Bay but that alternative simulation runs using different input variables would be required to extend the predictions to other zoogeographic provinces and marine climates (e.g. south of Cape Cod).

The Phase II work could also include a special effort to locate REMOTS® images within trawl door furrows in order to fill in data gaps identified in the 2002 trawling study. This can be done by mounting a downward-looking video camera on the REMOTS® frame. A shipboard video monitor can be used to guide the operator to deploy the camera when the vessel has drifted over a trawl door mark. In addition, by using digital cameras with high memory capacity, the SPI systems are now capable of taking hundreds of high resolution images, further ensuring that images would be collected within the door furrows. Because the trawl door furrows represent the most intense disturbance of the bottom, one may expect the greatest impact of smooth bottom otter trawl gear to be focused in these features. These same features are known to attract demersal fish and macrocrustaceans in their foraging activities (Burrows, et al., 2003).

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